

Transportation & Public Utilities Committee Meeting Agenda:
Sustainable Transportation and the Cambridge Bicycle Plan
October 20, 2015 / 3:30pm-5:30pm

I.

Committee Chair Dennis Carlone – **Opening Remarks**

II.

Cambridge Community Development Department Members Susan Rasmussen and Cara Seiderman - **Overview of Sustainable Transportation and the Cambridge Bicycle Plan**

III.

Public Comment

IV.

Council Questions & Discussion

Lopez, Donna

ATTACHMENT B

From: Jeremiah Schuur <j_schuur@yahoo.com>
Sent: Sunday, October 11, 2015 9:51 PM
To: Lopez, Donna; City Council
Subject: cambridge bike plan

I am a Cambridge voter writing to support the Cambridge bike plan.

I have one comment. As an emergency physician in Boston, I treat cyclists from Cambridge and surrounding towns who have been hit by cars. The single most important action that Cambridge can take is creating a network of separated bikeways to get around Cambridge. Thank you for creating the cycletrack on Western avenue!!! Now please work to build one on Mass avenue!

Jeremiah Schuur, MD
300 walden st.
cambridge, ma 02138

<https://twitter.com/JSchuurMD>

From: Steven Miller <semiller48@gmail.com>
Sent: Tuesday, October 20, 2015 9:15 AM
To: thecouncil@cambridgema.gov; Lopez, Donna
Cc: Seiderman, Cara
Subject: Please Support The Cambridge Bicycle Plan

City Councillors:

Our city has, once again, demonstrated leadership and vision. The new Cambridge Bicycle Plan is more comprehensive and sophisticated than almost any similar document for any municipality in the country. It incorporates the most important contemporary research and state-of-the-art designs. Developed through a best-in-the-nation process of public input and neighborhood-by-neighborhood discussion, it understands that bicycles are important not only for mobility but for personal, public, and environmental health as well as for sustainable economic development. There is no question that this document will circulate around the nation as an inspiration and model for hundreds of other cities. I urge the city council to endorse, approve, and – most importantly – push for and fund the rapid implementation of this proposal.

Cambridge has always had the long-term goal that anyone of any age, any ability, and any level of confidence should be able to get from anywhere to anywhere else by bike. And the incremental implementation of this powerful vision made the city an incredibly livable, non-car-dependent, and desirable places to live. I remember a former editor of Bicycling magazine riding over the Mass Ave bridge from Boston and saying, “entering Cambridge was like being able to breathe again.”

But during my own near-decade on the city’s Bicycle Committee we were stuck looking for opportunistic moments to slip in bicycle facility upgrades. The result was a disjointed set of bike lanes and off-road paths that kept the majority of potential cyclists – the so-called “interested but concerned” group – from leaving their cars at home. It is a real step forward, building on advances in the transportation engineering profession, to envision a city-wide seamless network of low traffic stress (or high bicycle comfort level) routes.

Of course, our streets serve many purposes and have enormous impact on the nature and quality of the surrounding land use, environment, and human interaction. Cambridge has always been a leader in understanding that many of those purposes do not involve cars –neighborhood socializing, children’s play, bus and transit access, walking, bicycling, and more. But we know that cars are still an important part of our transportation mix, with parking one of the more contentious areas of negotiation. Fortunately, we now understand enough about the differences between commercial and residential area parking dynamics and can learn from the proven ways to effectively deal with both needs to not have parking turn into a show-stopping problem. Still, it will take the courage of our convictions to insist that car uses take their place as only one among many uses, that car needs do not always take priority, and to demand that we all collectively open our minds to the compromises and creativity needed to find ways to serve everyone’s needs.

The city staff and the many many volunteers who work on these issues deserve enormous praise for the creation of the new Cambridge Bicycle Plan. I hope the city council recognizes the astounding value and importance of their work by passing, funding, and implementing this proposal.

Steven E. Miller

92 Henry Street.

Executive Director, Healthy Weight Initiative, HSPH, Dept. of Nutrition
Board of Directors, LivableStreets Alliance
cell: 617-686-1050

"The Public Way: Transportation, Health, and Livable Communities"

Lopez, Donna

ATTACHMENT

From: Matthew Cashman <mattcashman@gmail.com>
Sent: Tuesday, October 20, 2015 9:37 AM
To: thecouncil@cambridgema.gov; Lopez, Donna
Subject: I wanted to voice support for the Cambridge Bicycle Plan being discussed at today's meeting!

Hello,

I'm a resident of Cambridge (276 Windsor Street), and wanted to voice support for the Cambridge Bicycle Plan being discussed at today's Transportation Committee meeting.

Sincerely,

Matthew P. Cashman
276 Windsor Street
Cambridge, MA 02139

From: Gloria J. Korsman <gkorsman@yahoo.com>
Sent: Tuesday, October 20, 2015 11:14 AM
To: Lopez, Donna; thecouncil@cambridgema.gov
Subject: Cambridge Bicycle Plan

Dear Cambridge City Councillors,

I write to express my full support for Cambridge Bicycle Plan, and especially the proposed separated paths shown on p. 89. I commend the CDD's fundamental guiding principle: "to enable people of all ages and abilities to bike safely and comfortably throughout the city", as well as the CDD's process of gathering input from residents and people who travel in and through our city.

I live in North Cambridge and work at Harvard University, and ride a bike to reach most destinations in Cambridge, Somerville, and downtown Boston. I am not an athlete who gets a thrill out of riding in the street with cars at full speed, but rather a 50-year-old lady who hopes to cycle safely for many more years from point A to point B, ideally on a network of connected, separated cycle tracks. I enjoy traveling on Concord Ave, Vassar St, and Western Ave whenever possible. My stress level goes down when I no longer need to peer inside the cockpit of parked vehicles to see whether someone will fling open a door. I love the bike-specific traffic lights on Western Avenue that give me a head start at intersections. The location of the bus stops on Western Ave are great because they minimize potentially deadly bike-bus conflicts. These few, lovely cycle tracks in Cambridge are insufficient, because they lack connections to Mass Ave, Hampshire, etc.

On December 4, 2014, I attended an Open House about the plan at 1000 Mass Avenue, Room 152. Although the attendees I met were overwhelmingly in favor of the ideas that would later be published in the Cambridge Bicycle Plan, I met a few critics who favored keeping the *status quo* on our roads.

I encourage the Councillors to support the Cambridge Bicycle Plan, and to help lead to way to transportation that is cleaner, more sustainable, and healthier for all. Neither marriage equality nor universal health care had broad popular support when first proposed, but now more of us see these changes are good. I believe the same will happen with separated cycle tracks when everyone benefits from cleaner air, quieter streets, and fewer conflicts between bikes and motor vehicles.

Our built environment shapes our behavior. Most of my peers are too afraid to ride a bike in Cambridge. If we build for cars, we will get more cars. I'd rather we build for safe, active, clean transportation.

Thank you for your consideration of my views.

Sincerely,
Gloria Korsman
91 Montgomery Street #2L
Cambridge MA 02140
gkorsman@yahoo.com

Peace,
Gloria

gkorsman@yahoo.com
facebook.com/people/Gloria-Korsman/1488212811
linkedin.com/pub/gloria-korsman/7/687/82

Lopez, Donna

ATTACHMENT F

From: Michael Forden Walker <mfw@pinkmantis.com>
Sent: Tuesday, October 20, 2015 2:18 PM
To: Lopez, Donna; thecouncil@cambridgema.gov
Subject: Support for Bike Plan

I am a registered Cambridge voter and daily cyclist, and I support the Cambridge Bicycle Plan. The city has been making good progress making bicycling safer, but we have a long way to go.

Thank you!

=====
Michael F. Walker
284 Sidney Street
Cambridge, MA 02139
mfw@pinkmantis.com

Lopez, Donna

ATTACHMENT G

From: Kate Mytty <kmytty@mit.edu>
Sent: Monday, October 19, 2015 6:45 PM
To: Lopez, Donna
Subject: Cambridge Bicycle Plan

Hi Donna -

I saw the news that the Cambridge Bicycle Plan is in process and just wanted to say that I'm excited for the upcoming plan.

Many thanks,
Kate

Kate Mytty, MCP
MIT D-Lab Waste, Instructor
kmytty@mit.edu
402 676 9347

Lopez, Donna

ATTACHMENT H

From: Jeffrey Engler <jeffrey.engler@gmail.com>
Sent: Monday, October 19, 2015 6:26 PM
To: thecouncil@cambridgema.gov; Lopez, Donna
Subject: Bikes Bikes Bikes

Hi guys!

Just wanted to say I'm so excited you're supporting bikes in Cambridge with the Mass Ave, Hampshire, and Cambridge St. bike lanes. I love Cambridge, and I love bikes, and you're making an amazing combination.

Thank you!

Jeff

--

Jeffrey Engler
(917) 608-9785

Lopez, Donna

ATTACHMENT I

From: Peggy Gelin <mtgelin@verizon.net>
Sent: Monday, October 19, 2015 7:51 PM
To: Lopez, Donna
Cc: Kelley, Craig
Subject: Bike plan

Nice start to a long project. One request - bike lanes on Kirkland Street included in the plans. It is narrow, but I and many others bike there regularly despite the amount of bus and truck traffic. Parking on the north side of the street is not necessary. There is plenty of parking on the side streets north of Kirkland to accommodate any displaced parkers.

Peggy

Not responsible for wacko auto-corrections.

Lopez, Donna

ATTACHMENT J

From: Carol Lee Rawn <clrawn@gmail.com>
Sent: Monday, October 19, 2015 8:05 PM
To: Lopez, Donna
Subject: Strong support for Cambridge's bike plan

Dear Ms. Lopez,
Please forward to the City Council - thank you!

I strongly support Cambridge's new bike plan; a robust bike infrastructure helps ensure the safety and health of Cambridge's citizens, reduces congestion, and helps Cambridge meet its climate goals. My entire family uses cycling as a major mode of transportation in the city; a strong bike plan will help keep my daughters safe, and encourage cyclists of all ages. Thank you.

Carol Lee Rawn
59 Larchwood Dr. Cambridge, MA 02138

Lopez, Donna

ATTACHMENT K

From: deSolas <thedesolas@gmail.com>
Sent: Tuesday, October 20, 2015 6:13 AM
To: Lopez, Donna; Kelley, Craig
Subject: "Copenhagen Bike Paths - An Example To All Cities" on YouTube

https://youtu.be/ZtX8qiC_rXE

This video shows examples of some of Copenhagen's infrastructure including

- * Double bike lanes on busy bike routes
- * Prominent bike counters showing and recording daily bike traffic
- * LED lights embedded in streets alerting cars of bikes to mitigate right hand turn accidents
- * Traffic lights with advanced go for bikes
- * Bike security measures for bike parking
- * Lights times at 20 kph to allow bikes stop free access to the city

All of these measures could be implemented in Cambridge.

Best Regards,

David and Caroline de Sola.

19 year home owner
25 year resident

Lopez, Donna

ATTACHMENT L

From: rhaddleton@earthlink.net
Sent: Tuesday, October 20, 2015 1:16 PM
To: Lopez, Donna
Subject: email of support for the Cambridge Bicycle Plan

To the City Council:

Just a brief note expressing support for the Cambridge Bicycle Plan and cycletracks in Cambridge. I'd like my kids to be safe bicycling around town.

Thank You,
Russ Haddleton
322 Walden St. 02138

Lopez, Donna

ATTACHMENT M

From: Jessica Fosbrook <jessica.fosbrook@gmail.com>
Sent: Tuesday, October 20, 2015 1:16 PM
To: Lopez, Donna
Subject: In support of the citywide bicycle plan!

Hi - I'm a Cambridge resident and I bike every day. Please vote in favor of the citywide bicycle plan!

Thanks!
Jessica
650-353-0296

Hearing about the Cambridge Bicycle Plan
Cambridge, MA
October 20, 2015

Testimony from Anne Lusk, Ph.D.
Harvard T. H. Chan School of Public Health
AnneLusk@hsph.harvard.edu 617-432-7076

To increase biking in Cambridge and the safety of bicyclists, I would like to speak:

- 1) Against building more bike lanes in door zones, if possible (Chapter 4)
- 2) In favor of cycle tracks (separated bike lanes) (Chapter 4)
- 3) About encouraging bicycle parking inside residences and offices (Chapter 7)
- 4) To offer a suggestion for funding of cycle tracks.

1) Against building more bike lanes in door zones

An article published about the bike lanes in New York City, pointed out that bike lanes make riding safer for the pedestrian and car occupants but less safe for bicyclists.¹

2) In favor of cycle tracks.

Our research and the research of others indicated that cycle tracks are safer and more preferred.²⁻⁴

3) Encouraging bicycle parking inside residents and offices.

Our article on bicycle parking inside homes, offices, and schools is still under review but to increase bicycling, bylaws or incentives need to be in place to encourage:

- a. Private homes to have interior bike parking that is easily accessible and that involves few movements.
- b. Taller residential buildings to have bike parking inside each apartment unit
- c. Offices to have escalators that take a bike alongside or freight elevators that can accommodate bikes.
Bikes could then be parked by each desk in a slot.
- d. Schools to have lockers with bike slots by the lockers so bikes are parked inside.

4) Offer suggestions for funding of cycle tracks.

Now funding for bicycle facilities comes from local, state, or federal funds but, as evidenced by the few cycle tracks, funds are not readily available. There is also a great demand for transportation money to repair the existing roads and bridges. In 1905 when the car became popular, roads became clogged with parked cars because no one had planned where to put all the cars when not being driven. Now, cities face the same issue and half of a typical street paved surface area is taken up with parked cars. Cambridge charges only \$25 for a yearly parking permit and I would suggest that San Francisco could be copied. They charge \$111 for a yearly parking permit. In Boston, where 94,000 free permits are issues, charging \$111 a year for a parking permit would generate over \$10 million a year that could be put to building cycle tracks. This fee might also encourage people to not store their cars on the side of the road, freeing up space for the cycle track instead of leaving the parallel parked cars and painting door zone bike lanes.

I also would suggest implementing what I'm calling "Car Storage Incentive Zoning (CSIZ)" or allowing developers to build more, and not less, parking and to sell the parking to area residents who do not have off-street parking spaces. This also would then free up road space for biking. In 1905, Manhattan was building such parking garages for area residents. <http://academiccommons.columbia.edu/catalog/ac%3A165000>

I asked Legislative Aide, Collin Fedor, who works for State Representative Jeffrey Sanchez, if he could help me understand the ruling about charging for parking. I was asking for clarification about the MAPC web site that has this language. <http://www.mapc.org/resources/parking-toolkit/strategies-topic/residentialpermitparking>

I would suggest that "the cost of providing the service (see below)," i.e., storing a car on the side of the road, can be as high as \$111 a year, as in San Francisco.

Permit Fees (from the MAPC website)

The residential permit programs in Massachusetts all have quite low fees, from free to \$20 for the year. Massachusetts state law regulates how much a municipality can charge for residential permits, limiting the price of the permit to a statutorily-defined amount or the cost of issuing the permit. This means that the permit price cannot be used to restrain demand for resident parking under current state law.

Collin Fedor found out the specifics of the MAPC text:

Apparently the info from MAPC's website is correct, and stems from a court case in 1984: *Emerson College v. City of Boston* (<http://masscases.com/cases/sjc/391/391mass415.html>). In short, the case limits the amount a municipality can charge for a fee. It cannot exceed the cost of providing the service. Particular lines:

- With these considerations in mind, we turn to the question whether the AFSA charge is a fee. **Fees imposed by a governmental entity tend to fall into one of two principal categories: user fees, based on the rights of the entity as proprietor of the instrumentalities used**, Opinion of the Justices, 250 Mass. 591, 597, 148 N.E. 889 (1924), or **regulatory fees (including licensing and inspection fees), founded on the police power to regulate particular businesses or activities**, id. at 602, 148 N.E. 889. See *Boston v. Schaffer*, 9 Pick. 415, 419 (1830); P. Nichols, *Taxation in Massachusetts* 6-9 (3d ed. 1938). **Such fees share common traits that distinguish them from taxes: they are charged in exchange for a particular governmental service which benefits the party paying the fee in a manner "not shared by other members of society,"** *National Cable Television Ass'n v. United States*, 415 U.S. 336, 341, 94 S.Ct. 1146, 1149, 39 L.Ed.2d 370 (1974); **they are paid by choice, in that the party paying the fee has the option of not utilizing the governmental service and thereby avoiding the charge**, *Vanceburg v. Federal Energy Regulatory Comm'n*, 571 F.2d 630, 644 n. 48 (D.C.Cir.1977), cert. denied, 439 U.S. 818, 99 S.Ct. 79, 58 L.Ed.2d 108 (1978), and the charges are collected not to raise revenues but to compensate the governmental entity providing the services for its expenses
- Fees generally are charged for services voluntarily requested.
- Fees are legitimate to the extent that the services for which they are imposed are sufficiently particularized as to justify distribution of the costs among a limited group (the "users," or beneficiaries, of the services), rather than the general public."
- That revenue obtained from a particular charge is not used exclusively to meet expenses incurred in providing the service but is destined instead for a broader range of services or for a general fund, "while not decisive, is of weight in indicating that the charge is a tax."

So, the MAPC site is a bit confusing. It seems like the state doesn't necessarily have to approve a fee for a parking permit, but it limits the fee to the amount it costs to provide the service.

Bibliography

1. Chen L, Chen C, Srinivasan R, McKnight CE, Ewing R, Roe M. Evaluating the Safety Effects of Bicycle Lanes in New York City. *Am J Public Health*. 2012.
2. Lusk AC, Furth PG, Morency P, Miranda-Moreno LF, Willett WC, Dennerlein JT. Risk of injury for bicycling on cycle tracks versus in the street. *Inj Prev*. 2011;17:131-135.
3. Lusk AC, Morency P, Miranda-Moreno LF, Willett WC, Dennerlein JT. Bicycle Guidelines and Crash Rates on Cycle Tracks in the United States. *Am J Public Health*. 2013;103(7):1240-1248.
4. Thomas B, DeRobertis M. The safety of urban cycle tracks: a review of the literature. *Accident; analysis and prevention*. 2013;52:219-227.

Evaluating the Safety Effects of Bicycle Lanes in New York City

Li Chen, MS, Cynthia Chen, PhD, Raghavan Srinivasan, PhD, Claire E. McKnight, PhD, Reid Ewing, PhD, and Matthew Roe, MS

Bicycling is a healthy, environmentally friendly alternative to automobile use.¹⁻³ Yet, in the United States bicycling is primarily considered a recreational pursuit rather than a means of utilitarian travel. Among the nearly 140 million commuting trips made every day, slightly less than 0.5% are made by bicycle.⁴ Of trips for all purposes in the United States, only 1% are made by bicycle.⁵ Approximately 25% of all trips made are less than 1 mile, and 75% of these short trips are made by automobile.⁶ If some of these short trips were made by active modes such as walking or cycling, more people would reach the recommended 150 minutes of moderate-intensity physical activity per week (at present, fewer than 5% of adults engage in this amount of physical activity^{7,8}). Integrating physical activity into daily routines such as bicycling to work⁹ would also lead to sustained increases in habitual physical activity.⁷

The health and environmental benefits of cycling are clear and significant. However, bicyclists are vulnerable in that they share the same roadway with motorized vehicles. At intersections, they must maneuver their way through conflicting vehicular movements if they need to make a turn. Indeed, safety is a major concern that discourages people from bicycling.^{10,11} When a crash occurs, bicyclists are much more likely than motor vehicle users to sustain an injury, and the injury is likely to be more severe. Therefore, there is a need to gain a full understanding of the factors associated with cycling safety, particularly because many American cities are installing extensive bicycle lane networks to encourage the use of cycling for commutes.¹²

Studies of the safety effects of bicycle lanes in the United States date back to the 1970s. Some of the early studies, based on self-reported data from surveys of bicyclists or police reports, compared bicycle crash rates on different types of roadways such as roads with or without marked bicycle lanes and off-road trails. These studies reported lower bicycle crash rates on roads with bicycle lanes than on

Objectives. We evaluated the effects of on-street bicycle lanes installed prior to 2007 on different categories of crashes (total crashes, bicyclist crashes, pedestrian crashes, multiple-vehicle crashes, and injurious or fatal crashes) occurring on roadway segments and at intersections in New York City.

Methods. We used generalized estimating equation methodology to compare changes in police-reported crashes in a treatment group and a comparison group before and after installation of bicycle lanes. Our study approach allowed us to control confounding factors, such as built environment characteristics, that cannot typically be controlled when a comparison group is used.

Results. Installation of bicycle lanes did not lead to an increase in crashes, despite the probable increase in the number of bicyclists. The most likely explanations for the lack of increase in crashes are reduced vehicular speeds and fewer conflicts between vehicles and bicyclists after installation of these lanes.

Conclusions. Our results indicate that characteristics of the built environment have a direct impact on crashes and that they should thus be controlled in studies evaluating traffic countermeasures such as bicycle lanes. To prevent crashes at intersections, we recommend installation of "bike boxes" and markings that indicate the path of bicycle lanes across intersections. (*Am J Public Health.* 2012;102:1120-1127. doi:10.2105/AJPH.2011.300319)

roads without such lanes.¹³⁻¹⁷ However, causality cannot be inferred from these neighborhood-level studies because of confounding factors. Results from studies conducted at the roadway segment or intersection level have been mixed.¹⁸⁻²⁰

A major limitation of the existing studies is their lack of a rigorous quasi-experimental design that included a treatment group and a comparison group and that compared crashes in these groups before and after the installation of bicycle lanes.²¹ A report published by the Transportation Research Board and the Institute of Medicine described the existing literature on the built environment and physical activity as follows:

[M]ost of the studies conducted to date have been cross sectional. Longitudinal study designs using time-series data are also needed to investigate causal relationships between the built environment and physical activity.^{22(p77)}

The report went on to state that

[w]hen changes are made to the built environment—whether retrofitting existing environments or constructing new developments or

communities—researchers should view such natural experiments as 'demonstration' projects and analyze their impacts on physical activity.^{22(p229)}

The same limitations apply to later studies evaluating the impact of the installation of bicycle lanes on safety. In a before-after study of bicycle lanes on arterial roads in Madison, Wisconsin, Smith found an increase in bicyclist crashes on the 2 roads with bicycle lanes; however, the increase was insignificant relative to the increase in city-wide bicyclist crashes observed.¹⁸ Increases in crashes were also found in a before-after study of bicycle lanes in Oxford, England.¹⁹ To our knowledge, only 1 before-after study involved the use of both a treatment group and a comparison group to evaluate the safety impact of bicycle lanes.²⁰ This study, which focused on bicycle lanes installed in Copenhagen, Denmark, between 1988 and 2002, revealed increases in most types of crashes and injuries on roadway segments and at intersections with bicycle lanes; however, none of these increases were significant at the 5% level.

Using a quasi-experimental design that included a treatment group and a comparison group, we conducted a before–after analysis of 43 miles of bicycle lanes installed in the 5 boroughs of New York City from 1996 through 2006. The city's 5 boroughs vary greatly in built environment characteristics,²³ and this large variation helps strengthen the validity of our model results. We used generalized estimating equation (GEE) methodology²⁴ to account for correlations within repeated observations and to control factors (e.g., built environment factors) that could not be controlled through the use of a comparison group.

METHODS

We used a 2-stage design. In the first stage, we identified a comparison group comprising locations without bicycle lanes but with segment- or intersection-level characteristics comparable to those of the treatment group. The treatment group consisted of roadway segments in New York City where on-street bicycle lanes (not protected by a parking lane) had been installed from 1996 through 2006 (a total length of about 43 miles on 61 streets). Data on the dates during which bicycle lanes were installed and the locations of the bicycle lanes were available for each segment.

The dependent variable was police-reported crashes occurring on a roadway segment (a continuous section of roadway uninterrupted by a cross road or an intersection) or at an intersection. We distinguished among 5 categories of crashes: total crashes, multiple-vehicle crashes (crashes involving multiple vehicles but no bicyclists or pedestrians), bicyclist crashes (e.g., vehicle–bicycle collisions), pedestrian crashes (vehicle–pedestrian collisions), and injurious or fatal crashes (crashes that caused at least one injury or fatality).

For each category of the crashes described above, we calculated 2 categories of crashes for each segment or intersection: crashes within the 5-year period before the installation of bicycle lanes and crashes within the 2-year period after installation. Because a crash is a relatively rare event, use of the 5-year period before installation allowed us to capture more stable trends. Conversely, our use of a shorter period after installation allowed us to include more treatment group sites, because crash data were available

only up to 2008; thus, use of a 5-year post-installation period would not have allowed us to evaluate bicycle lanes installed in 2003 or thereafter. We used an offset variable to control for differences in the length of the before and after periods.

In the second stage, we used GEE methodology to apply Poisson and negative binomial regression models to the data set consisting of observations in the treatment group and the comparison group before and after the installation of bicycle lanes. We evaluated the safety-related effects of bicycle lanes in the treatment group via the coefficients estimated from the models.

Controls

We examined crashes on roadway segments and crashes at intersections separately because of their distinct natures. Intersections are high-risk locations for bicycle–vehicle collisions as a result of conflicts between bicyclists and motor vehicle users.²⁵ For this reason, we divided our comparison group into 2 subgroups: a segment-level subgroup and an intersection-level subgroup.

Our selection of the segment-level subgroup was based on 3 segment-level factors that have been found to have a significant impact on crashes: 1-way versus 2-way roads,²⁶ divided versus undivided roadways (if they are 2-way roadways),^{13,27} and number of travel lanes.^{28,29} Table 1 shows a comparison between the treatment group and the comparison group with regard to these characteristics. We further controlled the geographic distribution of the comparison group locations to resemble the distribution in the treatment group.

Because bicycle lanes were installed over a period of more than 10 years (from 1996 through 2006), the treatment group comprised bicycle lane segments installed in different years. In other words, the before period and the after period for different bicycle lane segments were different, although they were of the same length. As an example, the 5-year before period and the 2-year after period for bicycle lanes installed in 2000 were 1995 to 1999 and 2001 to 2002, respectively.

As a result of these differences, the treatment group was divided into multiple subsets defined by the year of installation. For each subset, we selected a set of untreated locations

by applying frequency-matching techniques to resemble the joint distribution of segment-level variables and the geographic distribution of the treatment group. After we identified each subset of the treatment group with a corresponding set of locations without bicycle lanes, we combined these untreated locations into the segment-level comparison subgroup.

Many of the bicycle lane segments in the treatment group were part of long corridors, whereas those in the comparison group were more likely to be scattered around the city. Therefore, we manually selected roadway segments that were parallel to those in the treatment group and added them to the comparison group. These procedures resulted in a segment-level subgroup of 1926 segments, corresponding to 579 bicycle lane segments.

From the segment-level comparison subgroup, we identified a second, intersection-level subgroup. We used control type (signalized or not)³⁰ and the number of roadway segments (arms) at the intersection,^{27,28} both of which have been found to have a significant effect on crashes at intersections, to select the intersection-level subgroup. A comparison of these attributes is shown in Table 1. We applied the same set of procedures just described to generate this comparison subgroup, which comprised 1653 intersections, corresponding to 578 intersections in the treatment group.

Model

We combined the identified segment- and intersection-level subgroups with the corresponding treatment group to generate 2 data sets, one for segment-level crashes and the other for intersection-level crashes. We then used the GEE method to apply Poisson or negative binomial models to these data sets. We used the Wald test to determine whether there was overdispersion in the crash data. If the crash data were overdispersed, we used the negative binomial model; otherwise, we applied the Poisson model. For the dependent variable (number of crashes during a period), each segment or intersection had 2 measures: crashes during the 5-year period before the installation of bicycle lanes and crashes during the 2-year period after the installation. The GEE method was applied to control correlations within repeated measures for crashes at a location in the before and after periods.

TABLE 1—Matched Characteristics of Locations in the Treatment Group and the Comparison Group: New York City, 1996–2006

	Treatment Group, No. (%)	Comparison Group, No. (%)
Segment characteristics		
Segments by borough		
Manhattan	80 (13.8)	259 (14.0)
Bronx	91 (15.7)	285 (14.8)
Brooklyn	273 (47.2)	940 (48.8)
Queens	135 (23.3)	432 (22.4)
Staten Island	0 (0.0)	0 (0.0)
Type of roadway		
1-way	288 (49.7)	979 (50.8)
2-way	291 (50.3)	947 (49.2)
Divided roadway		
No	502 (86.7)	1702 (88.4)
Yes	77 (13.3)	224 (11.6)
No. of travel lanes		
1	317 (54.7)	1067 (55.4)
2	212 (36.6)	689 (35.8)
3	14 (2.4)	47 (2.4)
4	30 (5.2)	101 (5.2)
≥5	6 (1.0)	22 (1.1)
Total	579 (100)	1926 (100)
Intersection characteristics		
Intersections by borough		
Manhattan	97 (16.8)	236 (14.3)
Bronx	95 (16.4)	221 (13.4)
Brooklyn	278 (48.1)	852 (51.5)
Queens	108 (18.7)	344 (20.8)
Staten Island	0 (0.0)	0 (0.0)
Control type		
Signalized	349 (60.4)	965 (58.4)
All-way stop	15 (2.6)	50 (3.0)
Stop on minor road	107 (18.5)	332 (20.1)
No control	107 (18.5)	306 (18.5)
No. of arms		
3	148 (25.6)	399 (24.1)
4	415 (71.8)	1218 (73.7)
≥5	15 (2.6)	36 (2.2)
Total	578 (100)	1653 (100)

Note. The treatment group consisted of roadway segments in New York City where bicycle lanes had been installed from 1996 through 2006. The comparison group comprised locations without bicycle lanes but with segment- or intersection-level characteristics comparable to those of the treatment group. The sum of the percentages for the different number of travel lanes in the comparison group and the treatment group is 99.9 because of rounding.

We included 2 dummy variables in the model: one denoting the crash changes from the before period to the after period in the treatment group and the other denoting the crash changes in the comparison group. (Full model specification is available in Appendices A

and B, available as a supplement to the online version of this article at <http://www.ajph.org>.) The 2 coefficients associated with the 2 dummy variables for the treatment group (*a*) and the comparison group (*b*) were of primary interest. The contrast between the 2 coefficients (*a* – *b*)

represented the difference in crashes from the before period to the after period for the treatment group versus the comparison group.

It has been hypothesized in previous research that higher levels of exposure (for example, more vehicle traffic, pedestrians, and bicyclists) and more conflicts (more conflicting movements between different road users) are associated with a higher number of crashes.³¹ Therefore, we entered a set of neighborhood-level and site-level (segment or intersection level) variables in the model to control exposure and conflicts. At the neighborhood level, we used daytime population density, retail density, and bicycle trip density to account for vehicular and bicyclist traffic exposures. We calculated daytime population density as the number of residents who live in a census tract plus the number of people who work in the census tract but live elsewhere, divided by the total census tract area. We calculated retail density as retail land use area divided by total census tract area. Finally, we calculated bicycle trip density as number of bicycle commuters divided by total census tract road length.

Site-level covariates included the presence of bus stops or parking on road segments, whether the segment was on a truck route, control type (signalized or not), and the number of arms at the intersection. These variables were included to account for conflicts between bicyclists and motorized vehicles.

In addition, we included an offset variable in the model—the number of years during which crash counts were collected—to account for differences between the 5-year before period and the 2-year after period. The coefficient of the offset variable was restricted to 1, under the assumption that crash counts would be proportional to the length of the before and after periods. To account for the difference in crashes between different groups during the before period, we also added 2 dummy variables to the model to alleviate the potential regression-to-mean effect, according to which locations with more crashes during the before period would be more likely to exhibit a reduction in crashes than those with fewer crashes in the before period.

RESULTS

Table 2 shows the number of crashes in the 5-year before period and 2-year after period

**TABLE 2—Roadway Crashes Before and After Installation of Bicycle Lanes, by Group:
New York City, 1996–2006**

Crash Type	Before Period (5 Years)		After Period (2 Years)		Change, ^b %
	Total	Average ^a	Total	Average ^a	
Crashes on segments					
Total					
Treatment group	827	0.2857	209	0.1805	-36.8
Comparison group	2164	0.2247	537	0.1394	-38.0
Vehicle crashes					
Treatment group	559	0.1931	137	0.1183	-38.7
Comparison group	1511	0.1569	367	0.0953	-39.3
Pedestrian crashes					
Treatment group	175	0.0604	43	0.0371	-38.6
Comparison group	446	0.0463	118	0.0306	-33.9
Bicycle crashes					
Treatment group	47	0.0162	19	0.0164	1.2
Comparison group	112	0.0116	25	0.0065	-44.0
Injurious or fatal crashes					
Treatment group	612	0.2114	153	0.1321	-37.5
Comparison group	1504	0.1562	363	0.0942	-39.7
Crashes at intersections					
Total					
Treatment group	4577	1.5837	1494	1.2924	-18.4
Comparison group	13450	1.6273	4124	1.2474	-23.3
Vehicle crashes					
Treatment group	3358	1.1619	969	0.8382	-27.9
Comparison group	10199	1.234	2925	0.8848	-28.3
Pedestrian crashes					
Treatment group	767	0.2654	333	0.2881	8.6
Comparison group	2213	0.2678	843	0.2550	-4.8
Bicycle crashes					
Treatment group	317	0.1097	155	0.1341	22.2
Comparison group	680	0.0823	244	0.0738	-10.3
Injurious or fatal crashes					
Treatment group	3748	1.2969	1196	1.0346	-20.2
Comparison group	10861	1.3174	3215	0.9725	-28.2

Note. The treatment group consisted of roadway segments in New York City where bicycle lanes had been installed from 1996–2006. The comparison group comprised locations without bicycle lanes but with segment- or intersection-level characteristics comparable to those of the treatment group.

^aAverage number of crashes per location per year.

^bChange in average number of crashes.

for the treatment and comparison groups. At the segment level, total crashes, multiple-vehicle crashes, pedestrian crashes, and injurious and fatal crashes all decreased in both groups. There was a slight increase (1.2%) in bicyclist crashes in the treatment group and a decrease in the comparison group. At the intersection level, total crashes, multiple-vehicle crashes,

and injurious crashes decreased in both groups. However, pedestrian and bicyclist crashes increased in the treatment group and decreased in the comparison group. The increases observed were likely due to higher exposure levels as bicyclists took advantage of the new bicycle lanes. We did not control for before–after differences in bicyclist and

pedestrian volumes because these data were not available.

The abbreviated model results for segment- and intersection-level crashes are shown in Table 3. We used negative binomial models for total crashes, multiple-vehicle crashes, pedestrian crashes, and injurious and fatal crashes because we detected overdispersion in these crash types. For bicycle crashes, no overdispersion was detected, so we used Poisson models. (Full model results are available in Appendices A and B, available as a supplement to the online version of this article at <http://www.ajph.org>.)

Table 3 shows the effects of bicycle lanes on segment-level crashes. The difference between *a* and *b* was negative for total crashes, multiple-vehicle crashes, pedestrian crashes, and injurious and fatal crashes; at the segment level, crashes decreased more in the treatment group than in the comparison group. For bicyclist crashes, the difference between *a* and *b* was positive, suggesting an increase in bicyclist crashes in the treatment group after the installation of bicycle lanes. However, the increase was not significant at the 5% level.

Table 3 also shows the effects of bicycle lanes on intersection-level crashes. The difference between *a* and *b* was positive for all 5 crash types, suggesting increases in crashes of these types in the treatment group after the installation of bicycle lanes. Again, none of these increases were significant at the 5% level.

Few existing studies evaluating the impact of bicycle lanes on safety have included built environment attributes. The estimated models (Tables A4 and A5, available as supplements to the online version of this article at <http://www.ajph.org>) show that most of the neighborhood-level variables were significant at the 5% level. We calculated elasticities (the percentage change in crashes in response to a 1% increase in a given attribute) to provide a better understanding of the roles that these built environment characteristics play in crashes (Table 4). An elasticity of 1 indicates that in response to a 1% increase in a particular attribute, the percentage change in crashes is exactly 1%.

Daytime population density had the largest effect on segment- and intersection-level crashes (in particular, pedestrian crashes). Every 1% increase in daytime population density was associated with a 0.738% increase in

TABLE 3—Estimates of Effects for 5 Types of Crashes on Road Segments and at Intersections: New York City, 1996–2006

	Total Crashes	Vehicle Crashes	Pedestrian Crashes	Bicycle Crashes	Injurious or Fatal Crashes
Crashes on segments					
Dispersion parameter ^a	1.365* (0.079)	1.601* (0.104)	1.543* (0.197)		1.398* (0.095)
Treatment group, T1 ^b (a)	-0.464* (0.083)	-0.484* (0.107)	-0.500* (0.205)	0.011 (0.263)	-0.475* (0.096)
Comparison group, T1 ^c (b)	-0.407* (0.064)	-0.426* (0.081)	-0.343* (0.119)	-0.401* (0.235)	-0.420* (0.071)
a - b, estimate (SE; 95% CI)	-0.057 (0.106; -0.265, 0.150)	-0.058 (0.134; -0.321, 0.205)	-0.157 (0.235; -0.619, 0.369)	0.412 (0.352; -0.279, 1.102)	-0.056 (0.120; -0.290, 0.178)
% change in crashes, estimate (SE; 95% CI)	-5.6 (10.1; -25.4, 14.2)	-5.6 (12.8; -30.7, 19.5)	-14.6 (21.0; -55.7, 26.6)	50.9 (58.3; -63.4, 165.2)	-5.4 (11.4; -27.8, 17.0)
Crashes at intersections					
Dispersion parameter ^a	0.966* (0.030)	1.080* (0.035)	0.975* (0.057)		1.010* (0.033)
Treatment group, T1 ^b (a)	-0.209* (0.040)	-0.339* (0.047)	0.090 (0.072)	0.201 (0.107)	-0.218* (0.044)
Comparison group, T1 ^c (b)	-0.264* (0.030)	-0.346* (0.034)	0.027 (0.050)	-0.047 (0.083)	-0.286* (0.032)
a - b, estimate (SE; 95% CI)	0.055 (0.050; -0.042, 0.153)	0.007 (0.058; -0.105, 0.120)	0.063 (0.088; -0.108, 0.235)	0.248 (0.135; -0.016, 0.514)	0.068 (0.055; -0.039, 0.175)
% change in crashes, estimate (SE; 95% CI)	5.7 (5.3; -4.7, 16.1)	0.7 (5.3; -10.7, 12.2)	6.5 (9.4; -12.0, 20.0)	28.1 (17.5; -6.3, 62.4)	7.0 (5.9; -4.5, 18.5)

Note. The treatment group consisted of roadway segments in New York City where bicycle lanes had been installed from 1996 through 2006. The comparison group comprised locations without bicycle lanes but with segment- or intersection-level characteristics comparable to those of the treatment group.

^aDispersion parameter is not applicable for bicycle crashes because bicycle crashes data were not overdispersed, and thus they were modeled by Poisson regression instead of negative binomial.

^bDummy variable: 1 if the data point comes from the treatment group in the after period and 0 otherwise; a is the coefficient of this dummy variable.

^cDummy variable: 1 if the data point comes from the comparison group in the after period and 0 otherwise; b is the coefficient of this dummy variable.

*P < .05.

segment-level pedestrian crashes and a 0.474% increase in intersection-level pedestrian crashes. These elasticities should be interpreted with caution, given that we were not able to control before-after differences in bicyclist and pedestrian volumes; density may increase bicyclist and pedestrian volumes much faster than it increases the number of crashes.

Retail density and bicyclist trip density appeared to exert the smallest effect. Elasticities for both were less than 0.1%, and the effect of retail density on intersection-level crashes was negligible. The effect of the density of bus stops was larger for intersection-level crashes (with most hovering around 0.2%) than for segment-level crashes (which were mostly much smaller than 0.2%). Subway ridership did not appear to have a large effect; it was not significant for intersection-level crashes, and for segment-level crashes the calculated elasticities were mostly around 0.02%. One neighborhood sociodemographic characteristic, percentage of residents living below the poverty level, was significant for intersection-level crashes; the number of crashes appeared to increase as the percentage of the population living below the poverty level increased.

DISCUSSION

Our results indicate that the installation of bicycle lanes does not lead to an increase in crashes despite the likely increase in the number of bicyclists after the addition of such lanes. In fact, all crash types on segments where there are treatments (except with bicyclists) decreased. We did not control for differences in bicyclist volumes before and after the installation of bicycle lanes because these data were not generally available. Existing literature shows a positive association between the presence of bicycle lanes and bicycle volumes.^{11,32–35} Based on New York City's Commuter Cycling Indicator (drawn from daytime bicycle volumes entering the city's central business district), bicycle volume increased during the study period, with a 51% increase from 1996 to 2006 and a 48% increase from 2006 to 2008 (the last years of the "after" period). This increase occurred at the same time as an expansion of the bicycle lane network, supporting the conclusion that bicycle volumes increased on these new bicycle lanes during this period.

TABLE 4—Elasticities of Neighborhood-Level Covariates for Crashes on Road Segments and at Intersections: New York City, 1996–2006

Neighborhood-Level Covariate	Covariate Value	Total Crashes	Vehicle Crashes	Pedestrian Crashes	Bicycle Crashes	Injurious or Fatal Crashes
Crashes on segments						
Daytime population density ^a		0.284	0.236	0.738	0.331	0.316
Average	52.517					
25th percentile	22.498					
50th percentile	38.437					
75th percentile	57.924					
Retail density						
Average	5.762	0.069	0.063			0.040
25th percentile	1.185	0.014	0.013			0.008
50th percentile	3.213	0.039	0.035			0.022
75th percentile	6.202	0.074	0.068			0.043
Bus stop density						
Average	83.892	0.159	0.143	0.101	0.025	0.168
25th percentile	47.143	0.090	0.080	0.057	0.014	0.094
50th percentile	80.386	0.153	0.137	0.096	0.024	0.161
75th percentile	115.028	0.219	0.196	0.138	0.035	0.230
Average subway ridership	2.698			0.027	0.019	
Average road bicycle trip density	3.261			0.026	0.062	
Crashes at intersections						
Daytime population density ^a		0.232	0.134	0.474	0.210	0.201
Average	61.478					
25th percentile	28.843					
50th percentile	44.831					
75th percentile	68.167					
Percentage below poverty level						
Average	0.267		0.116	0.144	0.124	0.175
25th percentile	0.122		0.053	0.066	0.057	0.080
50th percentile	0.244		0.106	0.131	0.114	0.160
75th percentile	0.382		0.166	0.205	0.177	0.250
Retail density						
Average	7.634				0.008	
25th percentile	1.921				0.002	
50th percentile	4.281				0.004	
75th percentile	8.368				0.008	
Bus stop density						
Average	97.062	0.165	0.116	0.223	0.233	0.175
25th percentile	60.533	0.103	0.073	0.139	0.145	0.109
50th percentile	91.771	0.156	0.110	0.211	0.220	0.165
75th percentile	127.898	0.217	0.153	0.294	0.307	0.230
Average road bicycle trip density	4.395			0.040	0.088	

^aIndependent of the value of this variable based on the model specification. Empty cells for some covariates indicate that the covariate is not in the model for the specific crash type.

In other words, if we could have properly controlled for differences in bicyclist volumes, we might have observed a significant

reduction in crashes in the treatment group. This also points to the need to collect before-and-after bicycle volume data not only for the

treatment group but also for the comparison group.

There are a number of possible reasons why we did not observe significant increases in crashes after the installation of bicycle lanes even though it is likely that bicyclist volumes increased significantly. Two primary possibilities are reduced vehicle speeds because of an increased awareness of bicyclists or lane narrowing and reduced conflicts because of the separation of vehicles and bicyclists.

Crashes at intersections appeared to increase, although not significantly; in interpreting this increase, it is important to note that the bicycle lanes included in this study were not designed as intersection safety treatments and generally did not involve design changes within intersections. For example, bicycle lanes discontinued at intersections and there are no lane markings at intersections that can guide bicyclists. We recommend 2 courses of action to increase the safety of bicycling at intersections. One is a “bike box,” an area reserved for bicyclists to wait at a red light ahead of vehicular traffic. The bike box is defined by a second stop line painted on the road approximately 10 to 15 feet in front of the stop line for cars.³⁶ When bicyclists encounter a red light at an intersection that has a bike box, they can wait between the two stop lines, in front of the cars in their lane of traffic. This increases the visibility of bicyclists stopping at red lights and allows them to clear the intersection before vehicular traffic does, thus reducing conflicts.³⁷ Our other recommendation is that markings indicating the path of the bicycle lane across the intersection or other intersection treatments be added at intersections to reduce conflicts.^{38–40}

Our results indicate that characteristics of the built environment should be included in safety studies. Built environment attributes have been largely excluded in existing studies assessing the effects of bicycle lanes.^{18–20} The significance of these variables in our models indicates that the mere use of a comparison group is often not sufficient to ensure between-group similarity.

Our 2-stage approach offers a number of advantages over Jensen's study,²⁰ seemingly the only previous study assessing crashes in both a treatment group and a comparison group

before and after installation of bicycle lanes. First, when a potential confounding factor is continuous, it is typically converted into a categorical variable for frequency matching when a comparison group is selected, and such conversion is often arbitrary. Second, although all potential confounding factors can be applied in the selection of the comparison group, this process usually results in a sample that is too small to allow useful evaluations. Finally, if confounding factors are used in selecting a comparison group, the effects of these factors can no longer be quantified. The second-stage regression models we applied controlled for factors that could not be controlled when selecting a comparison group, quantified their effects on crashes, and accounted for repeated measures.

In summary, our study, involving a rigorous quasi-experimental design, shows that installation of bicycle lanes does not lead to an increase in crashes, even with the likelihood of a greatly increased number of bicyclists using these lanes. To improve bicyclists' safety at intersections, we recommend the installation of bike boxes and markings that indicate the path of bicycle lanes across intersections, two features of more recently designed bicycle lanes in New York City and other cities. Our results also demonstrate the importance of controlling characteristics of the built environment in safety evaluation studies. ■

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Contributors

L. Chen collected data, designed the study, conducted the analysis, and wrote the article. C. Chen designed the study, interpreted the results, and wrote the article. R. Srinivasan assisted with data analysis and reviewed the

article. C.E. McKnight assisted with literature review and reviewed the article. R. Ewing participated in the literature review and reviewed the article. M. Roe assisted with data collection and reviewed the study results.

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Human Participant Protection

No protocol approval was needed because this study involved aggregate crash data examined at the segment and intersection levels.

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Risk of injury for bicycling on cycle tracks versus in the street

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ABSTRACT

Most individuals prefer bicycling separated from motor traffic. However, cycle tracks (physically separated bicycle-exclusive paths along roads, as found in The Netherlands) are discouraged in the USA by engineering guidance that suggests that facilities such as cycle tracks are more dangerous than the street. The objective of this study conducted in Montreal (with a longstanding network of cycle tracks) was to compare bicyclist injury rates on cycle tracks versus in the street. For six cycle tracks and comparable reference streets, vehicle/bicycle crashes and health record injury counts were obtained and use counts conducted. The relative risk (RR) of injury on cycle tracks, compared with reference streets, was determined. Overall, 2.5 times as many cyclists rode on cycle tracks compared with reference streets and there were 8.5 injuries and 10.5 crashes per million bicycle-kilometres. The RR of injury on cycle tracks was 0.72 (95% CI 0.60 to 0.85) compared with bicycling in reference streets. These data suggest that the injury risk of bicycling on cycle tracks is less than bicycling in streets. The construction of cycle tracks should not be discouraged.

Bicycling could address obesity, cancer, stroke, diabetes, asthma, mortality and pollution,^{1–2} however, the bicycling environment is a limiting factor. The predominant bicycle facilities in The Netherlands and Denmark are cycle tracks, or bicycle paths along streets that are physically separated from motor traffic, bicycle-exclusive and with a parallel sidewalk.³ Due to the separation from vehicles afforded by 29 000 km of cycle tracks in The Netherlands plus other initiatives,⁴ 27% of Dutch trips are by bicycle, 55% are women, and the bicyclist injury rate is 0.14 injured/million km.⁵ In the USA, 0.5% of commuters bicycle to work, only 24% of adult cyclists are women,⁶ and the injury rate of bicyclists is at least 26 times greater than in The Netherlands.⁵ The chief obstacle to bicycling, especially for women,⁷ children⁸ and seniors⁹ is perceived danger of vehicular traffic. This perceived danger from cars appears to be real,¹⁰ as corroborated by survey participants who prefer cycle tracks over roads.¹¹

Cycle track construction has been hampered in the USA by engineering guidance in the American Association of State Highway and Transportation Officials (AASHTO) 'Guide for the development of bicycle facilities'¹² which cautions against building two-way paths along, but physically separated from, a parallel road. AASHTO states that sidewalk bikeways are unsafe and implies the same about shared-use paths parallel to roads, listing numerous

safety concerns and permitting their use only in special situations. Cycle tracks, which can be one or two-way and resemble shared-use paths, are not mentioned in the AASHTO bike guide. A long-standing, and yet not rigorously proved, philosophy in the USA has suggested instead that 'bicyclists fare best when they behave as, and are treated as, operators of vehicles.'¹³ The details about cycle tracks in the Dutch bicycle design manual CROW³ and crash rate comparisons between the USA and The Netherlands⁵ have been dismissed by vehicular cycling proponents,¹⁴ with arguments of non-transferability to the American environment. Cycle tracks have been controversial, especially due to conflicting studies with warnings of increased crash rates.¹⁵ The warnings, which in the USA result in striped bike lanes but not cycle tracks, come without any substantial study of the safety of North American cycle tracks. Using existing crash and injury data from Montreal, Canada, a city with a network of cycle tracks in use for more than 20 years, this study compared bicyclists' injury and crash rates with published data and bicyclists' injury rates on cycle tracks versus in the street.

METHODS

We studied six cycle tracks in Montreal that are two-way on one side of the street. Each cycle track was compared with one or two reference streets without bicycle facilities that were considered alternative bicycling routes. One reference street was a continuation of the street with the cycle track; the remaining streets were parallel to the cycle track with the same cross streets as endpoints and, therefore, subject to approximately the same intersection frequency and cross traffic as the cycle track.

Injury and vehicle/bicycle crash rates per bicycle-kilometre

The injury and crash rates for each cycle track were determined from the emergency medical response (EMR) database¹⁶ and police-recorded vehicle/bicycle crashes and estimated on the cycle tracks per bicycle-km. Automated 24-h bicycle counts on Montreal cycle tracks are available for selected years, with 20–64 days in each sample from May to September. We used linear interpolation between the 2000 and 2008 samples to determine average daily use for the date ranges of the injury and crash counts. Average daily use was converted to annual use by multiplying by 200 'effective days' in the 1 April to 15 November bicycling season (when seasonal cycle tracks are open), recognising that



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bicycle use tends to be less in April, October and November than in the sampled months. Use estimates were converted to bicycle-km by multiplying by segment length and the fraction of the cycle track's length ridden per cyclist. This fraction, which ranged from 0.6 to 0.9, was determined using expert judgement considering the cycle track length and opportunities for turning on and off.

Relative Risk (RR) of injury for cycle tracks

The RR of the cycle track compared with the reference street was estimated using bicyclist counts and injuries from the EMR database.¹⁶ Although injury (EMR) and bicycle/vehicle crash data from police records overlap strongly, the injury data have been shown to be more exhaustive¹⁷ and were available for a longer period. Injury counts were determined for the 1 April to 15 November bicycling season and within 15 m of each street centerline. For comparability with exposure data, it was important to exclude individuals injured at intersections who may have been riding on a cross street; however, the EMR database does not indicate which street the injured cyclist was using. Therefore, using the police crash database we determined for each section studied the fraction of bicycle/vehicle crashes involving cyclists who were riding on cross streets, and reduced injury counts by that fraction.

Historical bicycle counts were available for the cycle tracks but not the reference streets. To obtain an unbiased measure of relative exposure, simultaneous 2 h bicycle counts were conducted at parallel counting sites on each cycle track and its reference street(s). Using a ratio of simultaneous counts eliminates systematic effects on bicycle use such as weather, time and day. The simultaneous counts were made during mild weather commuting hours in 2009.

The RR of injury for each cycle track was calculated as:

$$RR = \frac{\frac{\text{injuries}_{\text{track}}}{\text{bikes}_{\text{track}}}}{\frac{\text{injuries}_{\text{ref}}}{\text{bikes}_{\text{ref}}}}$$

where $\text{injuries}_{\text{track}}$ and $\text{injuries}_{\text{ref}}$ are the count of injuries on the cycle track and reference street(s), respectively, and $\text{bikes}_{\text{track}}$ and $\text{bikes}_{\text{ref}}$ are the corresponding cyclist counts.

Ninety-five percent CI were calculated using the variance of $\log(\text{ratio})$ based on a Poisson distribution for incidents. CI that did not include 1 were considered statistically significant. RR for all cycle tracks was calculated similarly using the summed data from all the observations.

Relative danger from vehicular traffic

Reference streets were selected with vehicular traffic danger (volume, speed, heavy vehicles) as similar as possible to their cycle track; however, it was impossible to achieve exact similarity. Therefore, to compare the vehicular traffic danger, we also calculated the ratio of motor vehicle occupant (MVO) injuries on the cycle track street to MVO injuries on the reference street. MVO injury counts are considered a surrogate for traffic danger a bicyclist might face on a given street apart from any treatment.

RESULTS

All six cycle tracks were two-way on one side of the street and separated from traffic by raised medians, parking lanes, or delineator posts. There were 8.5 injuries and 10.5 crashes per million bicycle-km. The Brébeuf and Maisonneuve cycle tracks stand out as safer than the other four (table 1).

Table 1 Injury and vehicle/bicycle crash rates for cycle tracks in Montreal, Quebec*

Cycle track	Configuration	Separation	Length† (km)	Length factor‡	Cyclists/day, 1999–2008 §	Bike-km/year (millions) ¶ **	Injuries/ year ††	Crashes/ year ††	Injuries per million bike-km	Crashes per million bike-km
1. Brébeuf (seasonal)	2-Way, 1 side of one-way street, street level	Delineator posts and parking lane	1.0	0.9	5316	0.96	3.9	1.8	4.1	1.9
2. Rachel	2-Way, 1 side of two-way street, street level	Raised median, delineator posts, parking lane	3.5	0.6	2581	1.08	12.6	17.0	11.6	15.7
3. Berri	2-Way, 1 side of two-way street, street/sidewalk level	Raised median, delineator posts, and parking lane	1.4	0.8	2778	0.62	7.8	10.2	12.5	16.4
4. Maisonneuve, w. island (seasonal)	2-Way, 1 side of one-way street, street level	Delineator posts	1.9	0.9	2379	0.81	1.9	2.8	2.3	3.2
5. Chr Colombe (seasonal)	2-Way, 1 side of two-way street, sidewalk level	Curb and (part) planting strip	3.7	0.7	921	0.48	6.7	9.2	14.1	19.3
6. René-Levesque	2-Way, 1 side of two-way street, street level	Raised median, delineator posts, parking lane	1.3	0.8	1108	0.23	2.8	3.2	12.3	13.9
All						4.18	35.7	44.0	8.5	10.5

*Whole segments of the cycle track were studied and not just intersections.

†Length of the section studied, which may be less than the entire cycle track length for comparability with reference streets.

‡Fraction of the study section's length ridden by a typical rider.

§Average for the May to September period over the period 1999–2008.

¶Year is the 7.5 month period (1 April to 15 November) when the seasonal cycle tracks are open.

**Demand is lower in April, October and November and, therefore, bicycle volume for a 'year' is assumed to be 200 times the daily volume.

††Injuries (data source — emergency medical response) between 1 April and 15 November for the period 1 April 1999 to 31 July 2008 divided by 9.53.

‡‡Bicycle—motor vehicle crashes (data source — police reports) between 1 April and 15 November 2002–6, divided by 5.

Table 2 RR of injury for cycle tracks compared to similar on-street routes for Montreal, Quebec*

Cycle track†	Reference street‡	Limiting cross streets	Length (km)	Cycle track		Reference street		RR (95% CI)¶
				2-h bike count	EMR-reported injuries§	2-h bike count	EMR-reported injuries§	
1. Brébeuf	St Denis (N)	Rachel — Laurier	1.0	1193	37	437	32	0.42 (0.26 to 0.68)
2. Rachel	Mont Royal	St Urbain — Marquette	3.5	990	120	613	63	1.18 (0.87 to 1.60)
3. Berri	St Denis (S)	Cherrier — Viger	1.4	763	74	134	27	0.48 (0.31 to 0.75)
4. Maisonneuve	Both	Claremont — Wood	1.9	547	18	176**	18	0.32 (0.17 to 0.62)
	Sherbrooke (W)					129	14	0.30
	Ste Catherine					47	4	0.39
5. Christophe Colomb	Both	Gouin — Jarry	3.7	407	64	122	19	1.01 (0.61 to 1.68)
	Saint-Hubert					45	9	0.79
	Christophe Colomb (S)	Villeray — Rosemont	2.3			77	10	1.21
6. René Levesque	Sherbrooke (E)	Lorimier — St Hubert	1.3	109	27	130	32	1.01 (0.60 to 1.68)
All			15.1	4009	340	1612	191	0.72 (0.60 to 0.85)

*Statistically significant comparisons are shown in bold.

†All cycle tracks are two-way on one side of the street.

‡An on-street bike route on a parallel street in close proximity of the cycle track.

§Injuries recorded by emergency medical response (EMR) services between 1 April 1999 and 31 July 2008 for the season 1 April to 15 November.

¶95% CI calculated using the variance of log(RR) based on a Poisson distribution.

**For comparisons having two reference streets, the total number of bicyclists is used from both streets.

Compared with bicycling on a reference street, the overall RR of injury on a cycle track was 0.72 (95% CI 0.60 to 0.85); thus, these cycle tracks had a 28% lower injury rate. Three of the cycle tracks exhibited RR less than 0.5, and none showed a significantly greater risk than its reference street. Overall, 2.5 times as many cyclists used the cycle tracks compared with the reference streets (table 2).

The relative danger from vehicular traffic of the cycle tracks compared with their reference streets was close to 1.0 overall, but with a wide range (table 3). Not surprisingly, the Brébeuf and Maisonneuve cycle tracks with lowest crash rate and relative injury risk (tables 1 and 2) also had the lowest relative danger from vehicular traffic (table 3). Yet even for the four cycle tracks on streets with vehicular traffic danger similar to or greater than its reference street, the cycle tracks still had less or a similar risk of injury.

DISCUSSION

Contrary to AASHTO's safety cautions about road-parallel paths and its exclusion of cycle tracks, our results suggest that two-way cycle tracks on one side of the road have either lower

or similar injury rates compared with bicycling in the street without bicycle provisions. This lowered risk is also in spite of the less-than-ideal design of the Montreal cycle tracks, such as lacking parking setbacks at intersections, a recommended practice.¹⁸

While the goal of this study was to consider both one and two-way cycle tracks, all of the Montreal cycle tracks were two-way with half the bicyclists riding in a direction opposite to that of the closest vehicular traffic, a practice not favoured by AASHTO. Although the Montreal cycle tracks were two-way, they had lower or similar risk compared with the road. The Dutch CROW bicycle guidelines suggest that one-way cycle tracks are even safer.³

The crash rate for Montreal's cycle tracks (10.5 crashes per million bicycle-km) is low compared with the few and inconsistent crash rates in the literature. When calculated to include only vehicle/bicycle crashes, these rates range from 3.75⁵ to 54¹⁹ in the USA and from 46²⁰ to 67²¹ in Canada. The injury rate (8.5 injuries per million bicycle-km) lacks comparable data in the literature, partly because few communities have accessible bicycle-incident ambulance records. Although the Brébeuf and Maisonneuve cycle tracks were safer, the sample of six cycle

Table 3 Relative danger from vehicular traffic*

Cycle track street	Reference street	MVO injuries†		Relative traffic danger of cycle track street (95% CI)‡
		Cycle track street	Reference street	
1. Brébeuf	St Denis (N)	8	90	0.09 (0.04 to 0.18)
2. Rachel	Mont Royal	86	69	1.25 (0.91 to 1.73)
3. Berri	St Denis (S)	127	116	1.09 (0.85 to 1.41)
4. Maisonneuve	Both	13	59§	0.22 (0.12 to 0.40)
	Sherbrooke (W)		72	
	Ste Catherine		46	
5. Christophe Colomb	Both	367	217§	1.69 (1.43 to 2.00)
	Saint-Hubert		268	
	Christophe Colomb (S)		166	
6. René Levesque	Sherbrooke (E)	196	205	0.96 (0.79 to 1.16)
All	All	797	756	1.05 (0.95 to 1.16)

*Statistically significant comparisons are shown in bold.

†Injuries to motor vehicle occupants recorded by emergency medical response (EMR) services between 1 January 1999 and 31 July 2008.

‡95% CI calculated using the variance of log(RR) based on a Poisson distribution.

§For comparisons having two reference streets, the average number of injuries of the reference streets is used.

MVO, motor vehicle occupant.

Table 4 Crash RR from Wachtel and Lewiston²² data with non-intersection crashes included*

	Sidewalk		Roadway		All		RR, sidewalk versus in-street (95% CI)†	p Value‡
	Riders	Crashes	Riders	Crashes	Riders	Crashes		
Intersection only§								
All cyclists	971	41	2005	48	2976	89	1.76 (1.16 to 2.68)	0.01
Bicycling in same direction as closest traffic lane	656	13	1897	43	2553	56	0.87 (0.47 to 1.63)	0.56
All crashes¶								
All cyclists	971	41	2005	79	2976	120	1.07 (0.73 to 1.56)	0.79
Bicycling in same direction as closest traffic lane	656	13	1897	71	2553	84	0.53 (0.29 to 0.96)	0.02

*Statistically significant comparisons are shown in bold.

†95% CI calculated using the variance of log(RR) based on a Poisson distribution.

‡Significance, calculated using the variance of log(RR) based on a Poisson distribution (for comparison with original article).

§Authors' original data.

¶Non-intersection crashes amounting to 26% of total crashes added to roadway crashes.

tracks was too small to determine which factors make some safer.

In one of the few comparisons of bicycling in the street versus bicycling on a separated path parallel to the street in the USA, Wachtel and Lewiston²² determined a relative crash risk of 1.8 for bicycling on sidewalks which had been designated as bike-ways, compared with bicycling in the adjacent street in Palo Alto, California. However, their study considered only intersection crashes, omitting non-intersection crashes that include being hit from behind, sideswiped, or struck by a car door. The authors, though, reported that 26% of cyclist-motor vehicle collisions city-wide in Palo Alto were non-intersection crashes. If non-intersection crashes are included to match this 26% proportion, reanalysis of the Wachtel and Lewiston²² data in the article shows that there is no significant difference in risk between the sidewalk bikeway and the street (table 4). For bicyclists riding in the same direction as traffic, as would be case with one-way cycle tracks, sidewalk bikeways carried only half the risk of the street. Therefore, the Wachtel and Lewiston²² data, when corrected to include non-intersection crashes, corroborate our findings that separated paths are safer or at least no more dangerous than bicycling in the street. Furthermore, as the most common cause of fatal bicyclist collisions in urban areas is overtaking,²³ it is probable that an analysis accounting for the severity of injury would be still more favourable towards cycle tracks.

Our study considered whole segments of cycle tracks and not just intersections, measured bicycle exposure directly, and included appropriate comparison groups. The study, though, only included analysis of six cycle tracks, all of which were two-way and in the same city, and lacked injury severity data. This

What this study adds

- ▶ Overall, 2 ½ times as many cyclists rode on the cycle tracks compared with the reference streets.
- ▶ There were 8.5 injuries and 10.5 crashes per million-bicycle kilometers respectively on cycle tracks compared to published injury rates ranging from 3.75 to 67 for bicycling on streets. The relative risk of injury on the cycle track was 0.72 (95% CI=0.60-0.85) compared with bicycling in the reference streets.
- ▶ Cycle tracks lessen, or at least do not increase, crash and injury rates compared to bicycling in the street.

research underscores the need for better bicycle counting and injury surveillance and for additional safety studies, particularly of one-way cycle tracks, intersections, injury severity and other factors that affect cycle track safety.

IMPLICATIONS FOR POLICY

Public health and bicycling advocates in the USA have faced a dichotomy, believing from surveys and European experience that cycle tracks encourage more bicycling, yet being warned that they lead to higher crash and injury rates. Our results suggest that cycle tracks lessen, or at least do not increase, crash and injury rates compared with the street. The construction of cycle tracks should not be discouraged.

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Competing interests None.

Ethics approval The Harvard School of Public Health IRB reviewed this protocol and found that approval was not required. The HSPH IRB made an exemption determination.

Contributors PGF had full access to the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. Conception and design: ACL and PGF. Acquisition of data: ACL, PGF, PM and LFM-M. Analysis and interpretation of data: ANL, PGF, PM, LFM-M, WCW and JTD. Drafting of manuscript: ACL, PGF. Critical revision for intellectual content: ACL, PGF, PM, LFM-M, WCW and JTD. Statistical expertise: ACL, PGF, PM, LFM-M, WCW and JTD. Administrative, technical or material support: WCW. Study supervision: PGF, WCW and JTD.

What is already known on this subject

- ▶ Individuals, in particular women, children, and seniors, prefer to bicycle separated from motor traffic.
- ▶ Cycle tracks (physically-separated bicycle-exclusive paths along roads) exist and continue to be built in The Netherlands where 27% of all trips are by bicycle and 55% of bicycle riders are female.
- ▶ Engineering guidance in the United States has discouraged bicycle facilities that resemble cycle tracks, including parallel sidepaths and sidewalk bikeways, suggesting that these facilities and cycle tracks are more dangerous than bicycling in the street.

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Risk of injury for bicycling on cycle tracks versus in the street

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Bicycle Guidelines and Crash Rates on Cycle Tracks in the United States

Anne C. Lusk, PhD, Patrick Morency, MD, PhD, Luis F. Miranda-Moreno, PhD, Walter C. Willett, MD, DrPH, and Jack T. Dennerlein, PhD

Bicycle riding has many positive benefits related to health¹⁻²⁰ as well as to transportation^{21,22} and the environment.^{23,24} Because the metabolic-equivalent intensity levels for bicycling are higher than those for walking,²⁵ bicycling can be even more beneficial than walking with respect to weight control,²⁶ all-cause mortality,^{27,28} and heart function²⁹ among adults, and with respect to physical fitness³⁰ and cardiovascular health³¹ among children. In the United States, 68% of the population is overweight or obese,³² and 34% of children and adolescents are overweight or at risk for being overweight.³³ Although bicycling is beneficial, US census data show that only 0.5% of US residents aged 16 years or older use a bicycle as a means of transportation to and from work, and only 24% of these bicyclists are female.³⁴ This low rate of cycling may be attributable in part to the lack of proper bike facilities.

In the Netherlands, where there are 29 000 km of cycle tracks,³⁵ 27% of trips are made by bicycle and, of total bicycle trips, 55% are made by female bicyclists.³⁶ In Montreal, Canada, where cycle track networks were initiated 20 years ago and there are now 63 kilometers of on-road cycle tracks along with 173 kilometers of park and riverside cycle tracks, bicycle volumes have increased tremendously.³⁷ In both the Netherlands³⁸ and Montreal,³⁹ detailed guidelines have long existed that support the implementation of cycle tracks. Recent research articles, reviews, and reports on bicycle facilities have noted the benefits of cycle tracks.⁴⁰⁻⁴⁶ However, other recent articles on bicycle facilities have described only the need for separation of bicyclists from cars⁴⁷ or have not included analyses or discussions of cycle tracks.⁴⁸⁻⁵²

In the United States, the guidelines of the American Association of State Highway and Transportation Officials (AASHTO) favor bicycling on roadways, even though most women, children, and seniors prefer separation from vehicles.^{36,53-60} Discouraged in these guidelines

Objectives. We studied state-adopted bicycle guidelines to determine whether cycle tracks (physically separated, bicycle-exclusive paths adjacent to sidewalks) were recommended, whether they were built, and their crash rate.

Methods. We analyzed and compared US bicycle facility guidelines published between 1972 and 1999. We identified 19 cycle tracks in the United States and collected extensive data on cycle track design, usage, and crash history from local communities. We used bicycle counts and crash data to estimate crash rates.

Results. A bicycle facility guideline written in 1972 endorsed cycle tracks but American Association of State Highway and Transportation Officials (AASHTO) guidelines (1974-1999) discouraged or did not include cycle tracks and did not cite research about crash rates on cycle tracks. For the 19 US cycle tracks we examined, the overall crash rate was 2.3 (95% confidence interval = 1.7, 3.0) per 1 million bicycle kilometers.

Conclusions. AASHTO bicycle guidelines are not explicitly based on rigorous or up-to-date research. Our results show that the risk of bicycle-vehicle crashes is lower on US cycle tracks than published crashes rates on roadways. This study and previous investigations support building cycle tracks. (*Am J Public Health.* 2013;103:1240-1248. doi:10.2105/AJPH.2012.301043)

is the building of bicycle facilities resembling cycle tracks, that is, physically separated and bicycle-exclusive paths adjacent to sidewalks. Past research articles on cycle track-related facilities, such as sidewalk bikeways and road-parallel shared-use paths,⁶¹⁻⁶³ have been used to discourage creation of cycle tracks in the United States. No studies have offered precise estimates of the existence and safety of US cycle tracks.

The US Department of Transportation policy statement recommends that the design of bicycle and pedestrian facilities follow the best currently available standards and design guidelines, such as AASHTO's *Guide for the Development of Bicycle Facilities* and *A Policy on Geometric Design of Highways and Streets* and the Institute of Transportation Engineers' *Design and Safety of Pedestrian Facilities*.⁶⁴ Thus, AASHTO guidelines, commonly available and used by state departments of transportation, have primarily directed the design of US bicycle facilities.

The new National Association of City Transportation Officials bike guide⁶⁵ includes cycle

tracks. However, without inclusion of cycle tracks in the commonly adopted AASHTO guide, without US-based cycle track research, and without public health and transportation policies in support of cycle tracks, it will continue to be difficult to create cycle track networks. Furthermore, in the public participation process often only a few individuals attend the evening hearings, and they include adjacent residents who are opponents of changes to the street and bicyclists who prefer the road as opposed to large numbers of potential bicyclists, including women, children, and seniors. The design is, therefore, often biased toward leaving the road virtually unchanged. As a result of these and many other historical reasons, the default bicycle facility in the United States remains a bike lane painted on a road,⁶⁶ in which many bicyclists do not feel comfortable⁶⁷ or safe.⁶⁸

We analyzed past and current state-adopted bicycle guidelines to assess the justifications for and level of rigor applied to recommendations for the use of bicycle facilities in the United States. Also, we determined, notwithstanding

the AASHTO guidelines, whether cycle tracks had been built in the United States and their characteristics. Finally, we examined whether the rate of vehicle–bicycle crashes on US cycle tracks was lower than published rates for bicyclists on roadways.

METHODS

In addition to collecting information on and analyzing state-adopted bicycle facility guidelines, we identified locations of cycle tracks, gathered data from local communities, and estimated bicycle–vehicle crash rates.

Bicycle Facility Guidelines

We studied Web sites and article bibliographies to identify US bicycle facility guidelines^{69,70}; we also examined all of the AASHTO guidelines (1974,⁷¹ 1981,⁷² 1991,⁷³ and 1999⁷⁴) regarding bicycle facilities. *Bikeway Planning Criteria and Guidelines*,⁷⁵ published in 1972 by the Institute of Transportation and Traffic Engineering at the University of California, Los Angeles (and later reprinted by the Federal Highway Administration), was also included. We systematically analyzed the guidelines, searching for sentences, references to research, bibliographical citations, and recommendations either favoring or discouraging the implementation of cycle tracks. Because bike facility preferences have been identified as a gender issue,^{53,55,56,76} we also assessed the gender of the guideline authors.

Identification of Cycle Tracks

To be defined as cycle tracks for this study, we required that cycle tracks be paved, parallel to vehicle travel lanes, 1 or 2 way, physically separated from motor traffic (i.e., separated by curbs or barriers to deter vehicles from entering), and distinct from walking paths; that they have data available or that could be obtained on crashes and bike counts; and that they not be completely adjacent to water (i.e., drivers would not drive over a cycle track to a beach). Thus, bike lanes denoted by paint alone and shared-use paths were not included.

We first identified US cycle tracks in February 2009 through a survey administered to listserv members of the Association of Pedestrian and Bicycle Professionals, which included 656 individuals throughout the United States

and Canada. As more cycle tracks were suggested and other cycle tracks were found through Web searches, other communities were contacted. Of 43 suggested facilities, we excluded 24 because they did not meet our criteria. For all suggested cycle tracks, we used Google street view maps to verify their existence and whether they were separated from traffic.

Data Collection

Between 2009 and 2012, we contacted numerous professionals (e.g., urban and bicycle-facility planners, police officers, parks and recreation coordinators, community and transportation officials) from all communities with cycle tracks to obtain information on cycle track design (e.g., configuration, type of separation, length), bicycle counts, and crashes. Data on bicycle counts (which ranged from 1-hour to monthly counts) were obtained from community reports^{77–80} or the community professionals we contacted. In the 2 cases in which counts were unavailable, we paid professionals to conduct the bicycle counts.

We obtained crash data on streets with cycle tracks from police departments, transportation divisions, official reports, and other sources. Almost all crashes were known to be police-recorded crashes. Only data on crashes resulting from an interaction between a vehicle and a bicyclist were included. Information on crashes involving pedestrians, other bicyclists, or fixed objects was not included because such crashes are not consistently recorded. Data on injury severity were not available for all cycle tracks studied, and thus not considered.

Estimation of Crash Rates

As with estimations of motor vehicle traffic volumes and determinations of average annual daily traffic,⁸¹ single bicycle counts must be adjusted for the count period and duration. Data from permanent cyclist counting stations can be used to estimate the repartition of cyclists across each month of the year, day of the week, and hour of the day. For each single bicycle count period, expansion factors were used to adjust the actual counts for time of day (f-hour), day of the week (f-day), and month (f-month), allowing an estimation of the average daily bicycle count (ADBC). We derived our expansion factors from 12-month counts taken with

24-hour continuous automatic bicycle counters on cycle tracks in Portland, Oregon, and Vancouver, British Columbia. To calculate the ADBC, we divided the hourly bike count on a given cycle track (denoted as B) by the appropriate expansion factors, as follows: $ADBC = B / (f\text{-hour} \times f\text{-day} \times f\text{-month})$. If cycle tracks had more than 1 hourly bike count on different days, we used averaged daily values from each count. The resulting ADBC was then multiplied by the length of the cycle track to derive average number of bicycle kilometers per day. This in turn was multiplied by 365 to determine average bicycle kilometers per year.

Detailed data on vehicle–bicycle crash locations, vehicle types, and bicycle movements were available only for the 5 New York City cycle tracks (from the New York State Department of Transportation). In New York City, bicyclists do not have to ride on cycle tracks; the Department of Transportation data allowed us to identify crashes occurring among bicyclists riding on roads and not on adjacent cycle tracks. We had determined that only a minority of crashes ($n = 9$; 22%) occurred on the roadway sections where the cycle tracks exist, but it was more complex to distinguish near the intersection whether the bicyclist was coming from the cycle track or riding on the road. Therefore, all reported vehicle–bicycle crashes on New York City streets with cycle tracks were included, even though some of the bicyclists may not have been riding on or coming from the cycle track.

Vehicle–bicycle crash periods (according to police records and community officials) ranged from 0.3 to 8.6 years. To estimate crash rates per million bicycle kilometers, we divided the number of vehicle–bicycle crashes by amount of bicycle exposure (average bicycle km/year \times crash period).

RESULTS

We analyzed and compared the bicycle facility guidelines, listed the characteristics of the 19 cycle tracks that met the inclusion criteria, and, after applying the expansion factors to the bicycle counts, estimated bicycle–vehicle crash rates.

Analysis of Bicycle Facility Guidelines

The 1972 *Bikeway Planning Criteria and Guidelines* document was authored by

TABLE 1—Bicycle Planning Documents and Recommendations Regarding Cycle Tracks: United States, 1972–1999

Document	Year	Authors Listed, No. (gender details)	Pages, No.	References Cited, No.	Endorses Cycle Tracks	Justification for or Against Cycle Tracks
<i>Bikeway Planning Criteria and Guidelines</i> ⁷⁵	1972	46 (only initials)	178 (plus 25-page appendix)	68	Yes	"Barriers at the interfaces can range from symbolic (e.g., striping), to physical (e.g., berms, median barriers, islands, fences). Symbolic barriers may be used to indicate to cyclists, drivers, and pedestrians their separate rights-of-way. However, symbolic barriers may be easily encroached either voluntarily or involuntarily by conflicting modes at the same grade. . . . In the absence of adequate horizontal clearance between the bikeway and the adjacent motor vehicle right-of-way a physical barrier is inherently safer than a symbolic one."
AASHTO documents <i>Guide for Bicycle Routes</i> ⁷¹	1974	22 (14 male, others only initials)	45	0	No	"A major disadvantage of this arrangement (cycle track) is that there are conflicts between the bicyclist and pedestrians wishing to enter parked vehicles, and for this reason, this type is not the preferred arrangement. . . . For the preferred arrangement . . . where the lane is between the parking lane and travelled way, the minimum width should be 3.5 feet (one-lane minimum) plus a 2 foot allowance for car door openings or a total of 5.5 feet."
<i>Guide for Development of New Bicycle Facilities</i> ⁷²	1981	0	31	0	No	"Bicycle lanes should always be placed between the parking lane and the motor vehicle lanes. Bicycle lanes between the curb and the parking lane create hazards for bicyclists from opening car doors and poor visibility at intersections and driveways, and they prohibit bicyclists from making left turns; therefore this placement should never be considered. [There should be at least] 5 feet minimum for bike lane by 8-10 feet parking."
<i>Guide for the Development of Bicycle Facilities</i> ⁷³	1991	~175 (~160 male)	44	13 (only 1 research-based)	No	"Bicycle lanes should always be placed between the parking lane and the motor vehicle lanes. Bicycle lanes between the curb and the parking lane can create obstacles for bicyclists from opening car doors and poor visibility at intersections and driveways, and they prohibit bicyclists from making left turns; therefore this placement should not be considered. [There should be] 5 feet for bike lane by 8-10 feet parking."
<i>Guide for the Development of Bicycle Facilities</i> ⁷⁴	1999	~145 (~140 male)	78	15 (only 1 research-based)	No	"Bike lanes should never be placed between the parking lane and curb lane. Bike lanes between the curb and parking lane can create obstacles for bicyclists from opening car doors and poor visibility at intersections and driveways and they prohibit bicyclists from making left turns. . . . The recommended minimum width of a bike lane by parked cars is 5 feet."

academicians in psychology, engineering, architecture, urban planning, housing, real estate, business administration, and management (Table 1). The report endorsed cycle tracks and included 68 citations, 16 from outside the United States. Only first initials were provided for the participating investigators, consultants, authors, advisors, and staff members; as a result, no data on the gender of the report's authors were available.

By contrast, the 1974, 1981, 1991, and 1999 AASHTO guidelines did not endorse cycle tracks. The reason given in the 1974 AASHTO guide was that cycle tracks posed a conflict with pedestrians crossing to parked vehicles. Other justifications were added in 1981 (and repeated in subsequent versions of the guidelines), including conflicts at intersections or driveways, that cycle tracks prohibited cyclists from making left turns, and that opening of passenger doors created hazards. The number of references cited in the AASHTO bibliographies ranged from 0 to 15, with only 1 research-based citation. Data on author gender were available only for the 1991 (91% male) and 1999 (97% male) guidelines.

Identification of Cycle Tracks

Nineteen cycle tracks met our inclusion criteria and had vehicle–bicycle crash data available (Table 2). Of these cycle tracks, 6 were located in warmer climates (Florida and California), 6 in colder climates (Minnesota, Colorado, Massachusetts, and Vermont), and the remainder in moderate climates (Oregon and New York). Six were 2-way cycle tracks on one side of the street, 7 were 1-way cycle tracks on both sides of the street, 2 were contra-flow cycle tracks (with bicyclists traveling toward cars), and the remaining 4 were 1-way cycle tracks on one side of the street. Ten were street level, and the remainder were above street level. Cycle track lengths varied from 0.16 to 4.83 kilometers (Table 3).

Crash Rates

Our findings showed that 55 bicycle–vehicle crashes were reported over a combined 57 years of cycle track observations. When we used our Portland expansion factors (Figure 1), the ADBC ranged from 21 cyclists (Apopka Vineland Road, Orlando, FL) to 2085 bicyclists (8th Avenue, New York City; Table 3). Eight cycle tracks had no reported crashes, whereas

8th Avenue in New York had 20 reported crashes over a period of 2.3 years. Overall, the estimated bicycle exposure (bicycle km/year × crash period) on all studied cycle tracks was 24 244 027 bicycle kilometers. Hence, with 55 crashes (and use of the Portland expansion factors), the overall crash rate was 2.3 (95% confidence interval [CI] = 1.7, 3.0) per 1 million bicycle kilometers. When the Vancouver expansion factors were applied, the crash rate was 2.1 (95% CI = 1.6, 2.8).

DISCUSSION

We analyzed 5 key state-adopted bicycle guidelines published between 1972 and 1999. *Bikeway Planning Criteria and Guidelines*, published in 1972 by the Institute of Transportation and Traffic Engineering at the University of California, Los Angeles, favored cycle tracks, but the subsequent AASHTO guidelines (initially published in 1974) did not. The 1972 guidelines were subsequently disfavored by some in the biking community⁶⁹; the AASHTO guidelines favored bike lanes and road cycling.

AASHTO recommended not building cycle tracks, or facilities on the sidewalk side of the parked cars, because of their lack of safety and movement constraints. Although it described cycle tracks as having possible conflicts with pedestrians crossing to parked vehicles or passenger doors opening, AASHTO did not cite research about such injuries on cycle tracks.

Instead of cycle tracks, the guidelines recommended bike lanes on the road side of parallel parked cars. Yet, even in the 1999 version of the AASHTO guidelines, no research was cited regarding the safety of bike lanes adjacent to parked cars. Door opening, in which a car occupant opens his or her car door when a bicyclist is passing, is associated with cyclist injuries. Door opening may be prevented or lessened with sufficient buffers between the parked cars and the cycle track or bike lane but such buffers require roadway width. With or without buffers, cycle tracks on the passenger side expose bicyclists less to opening car doors compared to bike lanes on the driver side, because not all cars have passengers but all cars have a driver. Additionally, while a bicyclist in the cycle track could swerve around or hit an opening

TABLE 2—Cycle Tracks and Their Characteristics: United States, 2002–2011

Cycle Track and Location	Configuration	Separation	Level
Calle Barcelona, Carlsbad, CA	1 way, 2 sides	Curb, planting strip	Raised
East Palomar Street, Chula Vista, CA	2 way, 1 side	Parking, curb, planting strip	Raised
Friars Road, San Diego, CA	2 way, 1 side	Raised median, curb stops	Street
Beach Street, Santa Cruz, CA	2 way, 1 side	Low rubber divider	Street
High Street, Santa Cruz, CA	1 way, 1 side, contra flow	Low rubber divider	Street
13th Street, Boulder, CO	1 way, 1 side, contra flow	Raised median	Street
Broadway, Boulder, CO	2 way, 1 side	Curb, planting strip	Raised
Apopka Vineland Road, Orlando, FL	1 way, 2 sides	Curb, planting strip	Raised
Vassar Street, Cambridge, MA	1 way, 2 sides, some blue paint	Parking, curb, planting strip	Raised
1st Avenue North, Minneapolis, MN	1 way, 2 sides	Two painted lines as buffer	Street
Loring Bikeway, Minneapolis, MN	2 way, 1 side	Curb, planting strip	Raised
1st Avenue, New York City	1 way, 1 side, green paint	Painted buffer, parking	Street
2nd Avenue, New York City	1 way, 1 side, green paint	Painted buffer, parking	Street
8th Avenue, New York City	1 way, 1 side, green paint	Painted buffer, parking	Street
9th Avenue, New York City	1 way, 1 side, green paint	Posts, painted buffer, parking	Street
Prospect Park West, New York City	2 way, 1 side, green paint	Painted buffer, parking	Street
Ayers Road, Eugene, OR	1 way, 2 sides	Mountable curb	Raised
Reed Market Road, Bend, OR	1 way, 2 sides, red	Mountable curb	Raised
Dorset Street, Burlington, VT	1 way, 2 sides	Curb, planting strip	Raised

TABLE 3—Vehicle–Bicycle Crash Rates on Cycle Tracks: United States, 2002–2011

Cycle Track and Location	Length, ^a km	Crash Report Period, ^b Year	Vehicle–Bicycle Crashes, ^c No.	Average Daily Bicycle Count ^d	Bicycle km/Year ^e	Exposure, ^f No.	Crash Rate ^g
Calle Barcelona, Carlsbad, CA	2.11	3.6 ^h	0	25	19 596	70 745	0.0
East Palomar Street, Chula Vista, CA	3.28	8.6	1	201	240 256	2 068 655	0.5
Friars Road, San Diego, CA	3.46	3.6	1	280	353 991	1 277 982	0.8
Beach Street, Santa Cruz, CA	1.22	1.0	1	695	309 627	309 627	3.2
High Street, Santa Cruz, CA	0.16	2.0	0	196	11 474	22 948	0.0
13th Street, Boulder, CO	0.34	3.5	0	1 157	143 601	502 605	0.0
Broadway, Boulder, CO	4.83	3.5	2	1 712	3 018 606	10 565 122	0.2
Apopka Vineland Road, Orlando, FL	1.93	4.0	0	21	14 630	58 522	0.0
Vassar Street, Cambridge, MA	0.32	5.0	1	564	65 911	329 555	3.0
1st Avenue North, Minneapolis, MN	1.13	1.8	4	330	136 295	249 873	16.0
Loring Bikeway, Minneapolis, MN	1.13	4.0	4	814	335 806	1 343 224	3.0
1st Avenue, New York City (1st to 34th)	2.65	0.3	3	1 854	1 793 312	597 771	5.0
2nd Avenue, New York City (34th to 1st)	2.60	0.5	5	1 620	1 537 153	768 577	6.5
8th Avenue, New York City (West 14th to West 34th)	1.57	2.3	20	2 085	1 194 847	2 787 976	7.2
9th Avenue, New York City (14th–33rd)	1.57	2.4	13	1 576	902 876	2 181 950	6.0
Prospect Park West (Bartel Pritchard Square to Union Street), Brooklyn, NY	1.51	0.8	0	1 654	911 816	683 862	0.0
Ayers Road, Eugene, OR	0.80	5.0	0	144	42 146	210 728	0.0
Reed Market Road, Bend, OR	1.19	4.0	0	109	47 438	189 752	0.0
Dorset Street, Burlington, VT	1.85	1.0	0	36	24 555	24 555	0.0
Total	34	57.0	55	...	11 103 935	24 244 027	2.3

Note. Totals may be rounded.

^aLength of cycle track studied (which, as a result of limited availability of crash and count data, may have been less than the entire cycle track length).

^bTime period during which crash data were available.

^cPolice- or community-reported crashes during the reporting period.

^dBased on bicycle counts (adjusted, via expansion factors, for time of day, day of week, and month) and duration of counting period.

^eLength of cycle track multiplied by average daily bike count multiplied by 365.

^fBicycle km/year multiplied by crash reporting period.

^gNumber of crashes divided by exposure (bicycle km/year multiplied by crash reporting period).

passenger door or in the bike lane swerve around or hit the driver door, a key difference is being beside the sidewalk versus being beside moving cars, trucks, and buses. In Toronto, there were 297 cases of dooring (11.6% of collisions, with 3.1% involving major injuries and 1 case resulting in a fatality) from 1997 to 1998, when bicyclists were riding on roads (cycle track networks did not exist).⁸² In Boston, Massachusetts, where bicyclists have also been riding on roads, motor vehicles accounted for the highest percentage of collisions among the city's bicycle messengers in 2001 (29%), followed by the opening of car doors (16%).⁸³

The AASHTO guidelines also did not cite research regarding preferences for bike lanes relative to cycle tracks. Recent studies have shown that female, child, and senior cyclists mostly prefer separation from vehicles^{36,53–60};

the AASHTO recommendations may have been influenced by the predominantly male composition (more than 90%) of the report's authors in 1991 and 1999. Finally, AASHTO did not report design alternatives for safely turning left from cycle tracks, solutions that existed on, for example, Dutch^{38,84} cycle tracks well before 1974.

The 19 US cycle tracks we examined totaled only 34 kilometers, a minuscule length compared with the 29 000 kilometers of cycle tracks in the Netherlands.³⁵ The overall estimated crash rate on the studied cycle tracks was 2.3 (95% CI = 1.7, 3.0) per million bicycle kilometers, which is low relative to reported crash rates on roadways in the United States and Canada. When calculated to include only vehicle–bicycle crashes on the road, published crash rates per million bicycle kilometers range from 3.75³⁶ to 54⁸³ in the United States and

from 46⁸⁵ to 67⁸⁶ in Canada. The wide range in reported rates for road cycling may be due to differences in study methods, case definitions, design features and context; however, all such rates of which we are aware are greater than the cycle track rates found in our study.

We may have underestimated crash rates because not all bicycle–vehicle crashes were reported. By contrast, rates may have been overestimated because crashes occurring in New York City could have involved bicyclists on roads as opposed to cycle tracks. For comparison, a recent study of 6 cycle tracks in Montreal relied on exhaustive police crash and ambulance injury data, and the safest Montreal cycle tracks had crash rates per million bicycle kilometers of 1.9 (Brébeuf) and 3.2 (Maisonnette).⁸⁷ The crash rate found here for US cycle tracks (2.3) is within this range.

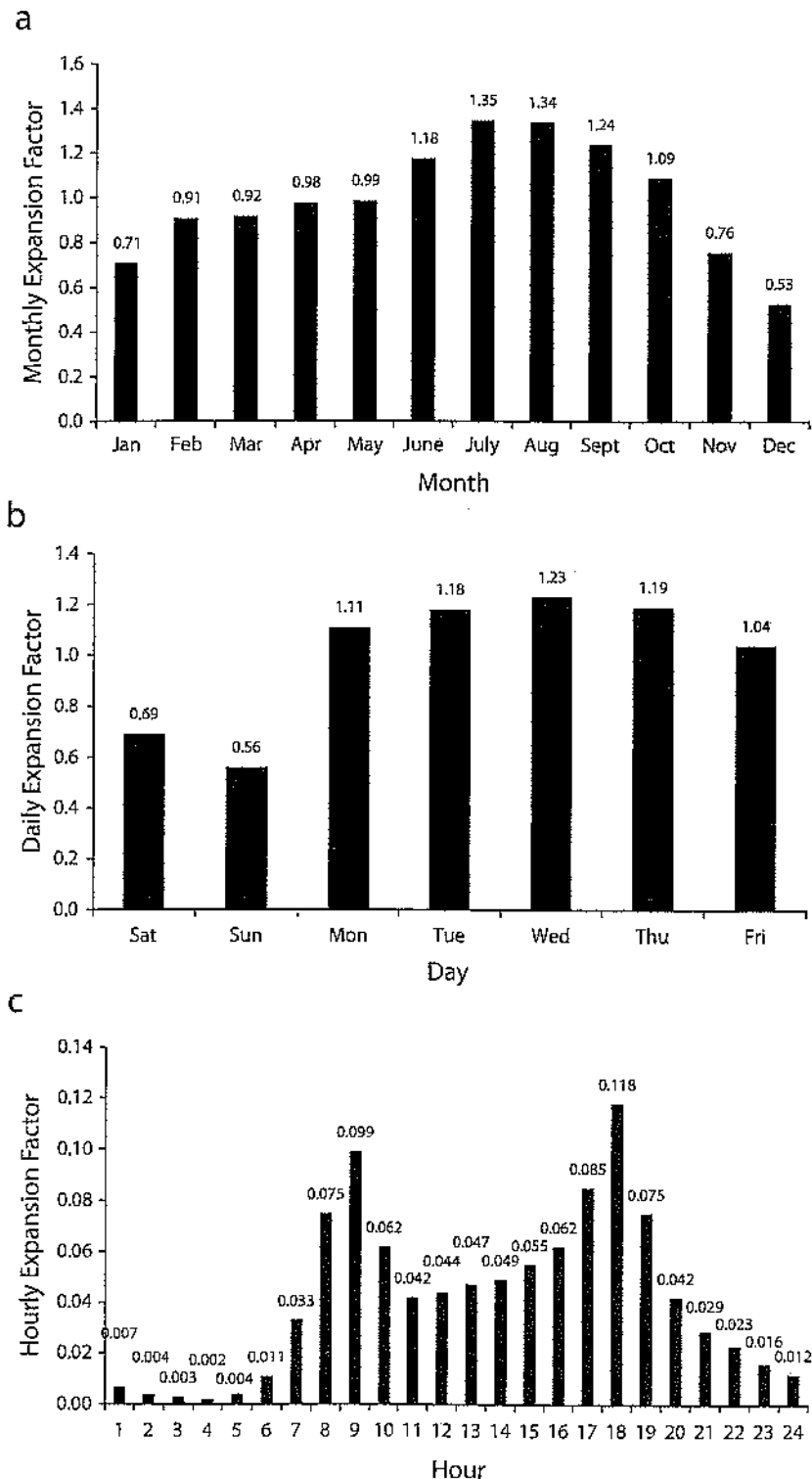


FIGURE 1—Expansion factors used to adjust bicycle counts for (a) month, (b) day, and (c) hour: Portland, OR, January–December 2010.

Two of the Montreal cycle tracks are located on major roads and had crash rates per million bicycle kilometers of 16.4 (Berri) and 19.3 (Christoph Colombo). Similarly, 2 of the US cycle tracks with the highest crash rates (1st Avenue in Minneapolis, MN, 16.0; and 8th Avenue in New York City, 7.2) are also along busy urban arterials. Overall in the Montreal urban study, there were 8.5 injuries and 10.5 crashes per million bicycle kilometers. In addition, there was a 28% lower injury rate on streets with cycle tracks than on reference streets (alternative routes without cycle tracks).

As a further comparison, data from New York City before and after installation of cycle tracks suggest that the rate of crashes with injuries decreased by 30% after installation of the 8th Avenue cycle track street section and 56% after the installation of the 9th Avenue section.⁷⁸ After implementation of the 2-way Prospect Park West cycle track, there was a 62% decrease in crashes with injuries, and the number of bicyclists riding on weekends doubled.⁷⁹ Similarly in Montreal, streets with cycle tracks had 2.5 times as many bicyclists as streets without bicycle facilities.⁸⁷

Our results contrast with 2 earlier US studies that discussed bicycling on sidewalks (which have also been categorized as cycle tracks).^{61,62} Moritz⁶¹ used a self-report sample of 2374 riders to collect data on number of kilometers ridden, percentage of use of bike facilities, and number of crashes according to type of facility. Only 0.8% of bicycle kilometers ridden and 12 crashes (4.4%) were reported as occurring in "other" settings (most often indicated as sidewalks or parking lots, with most respondents categorizing "other" as sidewalks). The relative danger index for sidewalk cycling was 5.30, compared with 1.26 for cycling on a major street; that is, bicyclists had a 5.30 times greater risk of crashing on sidewalks. A second study by Moritz⁶² involving 1956 riders revealed that only 9 crashes occurred in other settings and that 0.3% of bicycle kilometers ridden were in these settings. The relative danger index for cycling in other settings was 16.34, compared with 0.66 on major roads and 0.41 in bicycle lanes. These 2 studies are not sufficiently robust to allow conclusions about the safety of sidewalk bicycling or, by extension, the safety of cycle tracks.

In more recent research, a preinstallation–postinstallation study of cycle tracks in Copenhagen, Denmark, showed a 4% to 10% decrease in crashes and injuries occurring between intersections but an 18% increase in crashes and injuries occurring at intersections. According to the author, the latter finding was possibly due to the elimination of parallel parking and the fact that more drivers were turning to search for parking.⁶⁸ Another recent study, conducted in the Netherlands, suggested the creation of cycle tracks to reduce crash rates.⁴² A recent review of infrastructure studies on bicycle injuries and crashes showed that bicyclists are safer on roundabouts with cycle tracks,⁴³ and in the Netherlands walking and bicycling to school have been shown to be strongly associated with the existence of cycle tracks.⁴⁰

A review of peer-reviewed literature on bicycling and road safety conducted by authors in the Netherlands suggested that physically separated bicycle facility networks, as provided in the Netherlands (where 55% of bicyclists are female³⁶), lead to reductions in risk among cyclists.⁴² In Denmark, where cycle track networks are also provided, bicyclists have stated their preference for separation from vehicles and pedestrians.⁸⁹ By contrast, in the United States, where very few cycle tracks exist and bicyclists primarily have to ride with vehicles, rates of cycling have increased among men aged 25 to 64 years but have remained the same among women and decreased among children.⁴⁴

Strengths and Limitations

There are several strengths of this research. First, our historical perspective shows that recommendations against cycle tracks in the AASHTO guidelines were mostly duplicated from previous versions of the guidelines, without references to peer-reviewed findings. Second, the territory covered included the entire United States and, probably, most actual cycle tracks at the time the data were collected. Third, we took bicycle usage into account in estimating crash rates. Bicycle counts were uniformly expanded by applying the same factors, derived from US and Canadian cycle tracks, to all studied cycle tracks. These expansion factors were based on detailed and continuous bicyclist counts. Fourth, all reported bicycle crashes on New York City streets with cycle tracks

were included, even though an analysis of the crashes suggested that some occurred on the road and that some bicyclists were not riding on or coming from the cycle track.

The study involved several limitations. First, the guidelines analyzed were restricted to those most commonly adopted by states (mainly the AASHTO guidelines); however, they were the most critical guidelines with respect to implementation of cycle tracks. Second, crash data and bike counts were available for only a small number of US cycle tracks. Third, although some bicycle counts were extensive (e.g., New York City), others were 1-hour counts.

Fourth, the use of expansion factors from Portland and Vancouver may have resulted in bicycle usage being overestimated or underestimated. Fifth, although we attempted to collect data on all of the vehicle–bicycle crashes that occurred on each cycle track, reporting of crashes may have been incomplete. Sixth, for comparison crash rates on road bicycling we had to rely on studies from other contexts. Therefore, future research might estimate crash rates for bicycling on roadways in each of the US cities with cycle tracks, or another study design might be applied to compare bicycling on roads versus on cycle tracks. These limitations underscore the need for more systematic bike counts and crash data collection, as well as better descriptions of crash locations and trajectories. Our study serves as one of the many steps leading to a common understanding of bicycle facility guidelines and implementation of cycle tracks in the United States.

Conclusions

State-adopted recommendations against cycle tracks, primarily the recommendations of AASHTO, are not explicitly based on rigorous and up-to-date research. Our results suggest that, in the United States, bicycling on cycle tracks is safer than bicycling on roads. Furthermore, recent research shows bicyclists' preferences for cycle tracks. Stakeholders should consider the tremendous health benefits and safety of cycle tracks, especially given that their benefits have already been demonstrated in European and Canadian cities. Additional research on cycle tracks could identify optimal design features. ■

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Contributors

A. C. Lusk acquired the data and drafted the article. W. C. Willett and J. T. Dennerlein supervised the study. All of the authors contributed to the conception and design of the study, analysis and interpretation of the data, and critical revisions of the article.

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Human Participant Protection

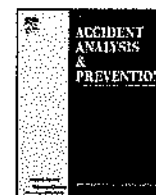
No protocol approval was needed for this study because publicly available data were used and no human participants were involved.

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Review

The safety of urban cycle tracks: A review of the literature

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ABSTRACT

Cycling has to be a safe activity, and perceived as such, if bicycle trips by all populations are to increase and the public health benefits are to be realized. A key characteristic of developed countries with a high cycling mode share is their provision of cycle tracks – separated bikeways along city streets – on major routes. This literature review therefore sought to examine studies of cycle tracks from different countries in order to elucidate the safety of these facilities relative to cycling in the street and to point to areas where further research is needed. The review indicates that one-way cycle tracks are generally safer at intersections than two-way and that, when effective intersection treatments are employed, constructing cycle tracks on busy streets reduces collisions and injuries. The evidence also suggests that, when controlling for exposure and including all collision types, building one-way cycle tracks reduces injury severity even when such intersection treatments are not employed. However, the extent of this effect has not been well examined, as very few studies both look at severity and control for exposure. Future studies of the safety of cycle tracks and associated intersection treatments should focus foremost on examining injury severity, while controlling for exposure. In the U.S., where the obesity epidemic and its health consequences and costs are well documented, the benefits of increased cycling should be a focus of research and policy development in order to provide the infrastructure needed to attract people to cycling while minimizing injuries.

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1. Introduction

A significant increase in the bicycle transportation mode share would improve public health by integrating physical activity into daily life. In order for the share of trips conducted by bicycle to grow substantially, cycling as an activity has to have real and perceived safety. The Netherlands and Denmark enjoy high bicycling mode shares (26% and 19%, respectively) (Netherlands Ministry of Transport, 2009) and are also characterized by the provision of cycle tracks as the predominant form of cycling infrastructure on major streets. In contrast, the bicycling mode share in the U.S. is much lower (around 1%) and yet cycle track construction is discouraged in the roadway design guidance and policies of many U.S. states.

Most influential on a national level is the American Association of State Highway and Transportation Officials (AASHTO) *Guide for the Development of Bicycle Facilities* (2012), which lacks guidance for the design and operation of cycle tracks. It does contain guidance on the design of shared use paths which may be exclusively for the use of different types of cyclists and separate from the sidewalk or pedestrian path. However, the Guide recommends that shared use paths adjacent to roadways (side paths/cycle tracks) be placed a minimum of 5 feet from the edge of the motorized vehicle traveled way, regardless of whether a curb is present, and with the shoulder or parking lane not counting toward that 5 feet. Following this recommendation would preclude developing cycle tracks in urban environments where space is constrained and where the cycle track would have therefore been placed directly behind the curb (between the curb and the sidewalk) or between the parking lane and the curbed sidewalk.

The purpose of this literature review is to examine the major studies on the safety of cycle tracks in order elucidate the safety record of these facilities relative to cycling in the street and to point to areas where further research is needed.

This review will describe the methods employed for the various studies and their findings, as well as discuss their limitations. Since many of the studies showed a higher overall intersection collision rate associated with cycle tracks, another important focus of this review is the study results of intersection safety measures and treatments developed for cycle tracks. Also, this review pays careful attention to whether studies controlled for exposure and examined injury severity, given that intersection collisions are less likely to result in a fatality than bicyclists being hit from behind (overtaking collisions) between intersections in urban areas (McCarthy and Gilbert, 1996), and that cycle tracks tend to increase biking trips where they are built.

2. Definition of terms

The term “cycle track” should be defined relative to other terms so that studies can be compared fairly. An urban cycle track is a bicycle path alongside a major city street that is separated from the motorized vehicle traffic by a physical barrier. It is distinct from the

sidewalk, being generally placed between the auto lanes and the sidewalk, but separated from auto traffic by a raised curb, planting strip or on-street parking. A cycle track may be one-way, placed on each side of the street, or two-way and placed on one or both sides of the street. Cycle tracks are distinct from multi-use or shared use paths. The terms multi-use path and shared use path are used interchangeably in the U.S. to refer to a two-way bicycle path that is open to pedestrians (with or without a separate pedestrian path) and is either away from roads or set back from the roadway, such as in a park or along a parkway or former railroad right-of-way (AASHTO, 2012; Teschke et al., 2012). Table 1 provides further clarification.

3. Methods

In total, 23 papers on the subject dating from 1987 were located. All of these were from Northern Europe with the exception of one from Canada. The reason for this geographic distribution is that North America has relatively few cycle tracks to study, although more are being built. Some studies of U.S. sidewalk riding have been conducted, but these are excluded from this review because of the large differences in facility design between sidewalks and cycle tracks and therefore the lack of comparability of the studies. For example, an often cited study by Wachtel and Lewiston (1994) compared riding on sidewalks designated as bikeways to riding in the parallel street in Palo Alto, California. Its analysis was limited to intersection crashes so it did not provide an overall safety comparison. The sidewalks on the studied roadways were signed “Bikes May Use Sidewalk” but were not designed or modified to be bicycle paths, side paths or cycle tracks. This study is therefore excluded from the literature review.

Note that, in the European countries where the studies reviewed here were done, multilane roads are relatively rare compared to the situation in the U.S. and Canada. Caution should be used in extrapolating the results, in terms of statistical changes, to North American locations. Instead, the results of this review should be taken as a general guide regarding the direction of effect of these facilities, and intersection design treatments for them, and to where further North American research is needed.

4. Discussion

4.1. Early studies and bicyclist exposure

Many of the early studies on the safety of cycle tracks had a significant limitation in that they did not control for the amount of bicycling, also called bicyclist exposure. Although these studies reported that crashes and injuries increased with the construction of cycle tracks, the rates may have actually gone down relative to the volume of cyclists, given that building cycle tracks on streets increases their use by cyclists. In other words, the relative risk associated with using a cycle track may have actually been less. Early studies that did not control for exposure include an unpublished one by the West Berlin Police Department (1987), an unpublished

Table 1
Comparison of bike paths and cycle tracks.

	Multi-use/shared use paths	Cycle tracks
Setting	Built-up & rural areas	Built-up areas
Type of roadway	No consensus; typically built wherever right of way was available, often abandoned rail lines	Typically on major streets between traffic lane or on-street parking and sidewalk
Directional	Two-way (unless two parallel paths are built, which is rare)	Can be one-way or two-way
Shared use with pedestrians	Yes, shared use all the time (even if optional adjacent pedestrian path is provided)	No shared use, bicycles only
Intersection treatments	Historically, not addressed very consistently	Raised cycle crossings, colored crossings; Major intersections: bicycle signal heads with exclusive phase

study of Danish cycle tracks by Bach et al. (1988), which found an absolute decrease in bicyclist collisions between intersections even without controlling for exposure, a Danish hospital-based study by L.B. Larsen (1994), and a Swedish study on injured bicyclists visiting a physician or dentist by Eilert-Petersson and Schelp (1997). The authors of the West Berlin study acknowledged the problem of not accounting for exposure when they wrote, “the false impression might arise that streets with side paths are more dangerous than those without. To counter this impression, note that about 90% of the side path network (about 450 km) is on major streets with priority at intersections (about 720 km). Precisely these streets have a high traffic volume, and they also attract bicyclists to some extent” (pages 7–8). Larsen implicitly acknowledged relative risk when he concluded that “it is necessary to separate the bicyclists from the ‘hard’ road traffic [motorized vehicles not including mopeds]” (page 31) by increasing the number of cycle tracks. The paper clarified that special care has to be taken at roadway crossings, but did not describe or recommend specific treatments.

4.2. Early Dutch studies and use of cycle tracks by moped riders

Until late 1999, moped riders were entitled by law to use cycle tracks in The Netherlands. A pair of Dutch studies, both released in 1988, found safety problems with this practice. Wegman and Dijkstra of The Netherlands Institute for Road Safety Research (1988) found that cycle tracks inside built-up areas are safer for bicyclists and moped riders between intersections, but have an increased collision rate at intersections compared to streets without cycle tracks, with moped riders presenting a risk for bicyclists. The paper reported that, within built-up areas, “on cycle paths moped riders have relatively many accidents with cyclists and pedestrians.” The paper recommended that cycle paths be ended before an intersection and that moped riders be prohibited from using cycle tracks in urban areas. Even with the use of cycle tracks by moped riders, another study for The Netherlands Institute for Road Safety Research, this one by Welleman and Dijkstra (1988), found that the increased injury risk at the intersections was offset by a decreased risk on the links between the intersections such that the overall injury risk of using cycle tracks did not significantly differ from riding in mixed traffic on the street.

As a result of these studies, two changes in cycle track policy and design were made in The Netherlands. First, in December 1999, a law was finally passed to prohibit moped riders from using cycle tracks in urban areas except where the speed limit for motorized traffic is 70 km per hour or higher. Second, rather than truncate cycle tracks in advance of intersections and force riders into traffic, the cycle track crossings at many intersections were raised, effectively creating a speed hump to slow turning auto traffic. Studies of this treatment are further discussed below.

4.3. Studies limited to intersection collisions

4.3.1. “Expert” Opinion Model

A study by Garder et al. (1994) attempted to draw conclusions about the relative safety of bicycle paths at signalized intersections in Sweden by using the Bayesian method to combine the opinions of bicyclists and “experts” with the results of four previous studies: a master’s thesis by Ahadi and Nassiri (1986) and unpublished work by Nettelblad (1987), Leden (1988) and Linderholm (1990). Specifically, Garder attempted to show the cyclist’s risk of a collision at signal controlled through-going bicycle paths, with the cycle crossing of the side street at 6 m away from the parallel main street (to allow space for a motorist to complete the turn but wait for the cyclist to cross), compared to signal controlled intersections with mixed traffic and a refuge on the side street wide enough for the cyclist to stop within it. Although the Garder paper refers to the

facilities as “bicycle paths” rather than cycle tracks, the four studies chosen by the author all use data from collisions in built-up areas and therefore seem appropriate to include in this literature review.

The studies that Garder used had results that varied widely, with the cycle track presenting an intersection collision risk from 0.78 (Ahadi) to 8.6 (Leden) times the intersection collision risk without a cycle track. Leden’s results were based on collisions reported in a survey of school children, so they may have included a number of very minor collisions not reported to the police, which could account for Leden’s figure being so much higher than what other studies have shown. Garder cautions that one reason for the variability in study results is that “the actual risk varies from intersection to intersection. Local conditions, bad signal timing, etc. give very high risks at some intersections.” (page 438).

The Garder paper also tried to factor the opinions of bicyclists and “experts” into the combined results. Although the authors estimated that introducing a cycle track increases the intersection collision risk for a passing bicyclist by 40%, this figure is speculative to some degree given that it is influenced by individual opinions. The conclusion of the paper is that “bike paths, in general, enhance safety between the intersections” (page 439), but that they should merge onto the street (illustrated as an on-street bicycle lane in the report) about 20 meters before the intersection. Note that an unpublished paper by L. Herrstedt et al. (1994) stated that the treatment of truncating cycle tracks 20–30 m before an intersection, where they become bicycle lanes, was unpopular in Denmark. Assuming that this holds true in Sweden as well, it is noteworthy that a later study by Garder et al. (1998) found that the alternative treatment of continuing the cycle track all the way to the intersection, and through it with a raised bicycle crossing, is effective at reducing cyclist crashes. Both the Herrstedt and Garder papers are reviewed in Section 3.6.2. A limitation of this paper, and of the prior studies it cited, is that they did not examine the overall difference in bicycle collision severity, for all collision locations, for streets with cycle tracks compared to those without.

4.4. Before–after studies using a comparison group

In an unpublished paper, Jensen (2007) presented the results of a before-and-after study of the safety of one-way cycle tracks and lanes in Copenhagen. The approach was to compare the observed change in crashes and injuries following cycle-facility introduction to model predictions based on a comparison group of unchanged roads. The cycle tracks studied were constructed from 1978 to 2003. The prediction model was based on the cycling/moped traffic volume, the motorized vehicle traffic volume, and the historical trend in collisions and injuries of a comparison group from 1976 through 2004. The reported results suggest that the introduction of cycle tracks reduced some collisions relative to the comparison-based predictions (rear-end crashes and associated injuries as well as crashes with left-turning bicycles/mopeds and with parked motor vehicles), while raising others (crashes with right-turning vehicles, between bicyclists/mopeds and other bicyclists/mopeds, and between bicyclists/mopeds and pedestrians). Jensen shows that much of the increased collisions between bicyclists and pedestrians involves crashes with entering or exiting bus passengers. Note that in Copenhagen bus passengers exit directly onto the cycle track. This type of collision could be largely prevented if the cycle tracks were separated from the bus stops by a platform, as is done elsewhere.

One problem with the study is that the comparison group model did not accurately predict changes in problems when it was tested on the treatment streets. Specifically, the model was not adjusted after it underpredicted bicyclist crashes and injuries in testing it on a comparison of the before–before to the before period at locations where the cycle tracks were later constructed. Such a calibration

would have likely changed the direction and magnitude of the results for some or many of the different crash types and would have shown more favorable results for the streets with cycle tracks. When looking at the raw data, the observed after period with cycle tracks shows a decrease in fatalities and almost all injury types, so the accuracy of the model is essential for understanding the effect.

One consideration regarding the model accuracy is the similarity of the comparison group to the test group. Cycle tracks in Copenhagen tend to be constructed on major routes where traffic volumes and speeds are higher. It is because of these characteristics that separation for bicyclists is provided. If the comparison group tended to include narrower streets with lower traffic volumes, then the collision and injury trend for this group would not be a good predictor of the trend to expect where cycle tracks are constructed. The paper states that “an effort was made in order to avoid consequences of larger differences between general comparison group and treated roads, where bicycle facilities were applied. Trends for different types of crashes and injuries of the general comparison group were compared.” Although the paper refers to comparing crash trends, it does not indicate the extent to which the roads in the comparison group had similar traffic volumes to those in the treatment group.

Another consideration is the accuracy of the model's use of changes in traffic volume to predict changes in crashes and injuries. Jensen writes that, “In the Copenhagen case, many of the studied roads/intersections are in the far end of the traffic volume axis, i.e. much trafficked, and we are therefore close to or outside the boundaries of the crash models' valid area.” He uses a stepwise methodology taking into account the trend in the comparison group and regression to the mean, but these do not address the accuracy of the traffic model on high traffic volume streets. A more general related concern has to do with the model's prediction of reduced crashes in response to a reduction in traffic volume from cycle track construction. This in effect penalized cycle tracks for decreasing motorized traffic volume by increasing the expectation as to how the cycle tracks should perform in reducing crashes.

In addition, although the bicycle traffic volume was included in the model, the before- and after-period crash results were not divided by the bicyclist volume in each period to assess the change in relative risk. This calculation, together with the above-described calibration of the model, would have likely changed the study results and conclusions. Finally, as Jensen noted in his paper, “making these facilities resulted in more cycling and less motor vehicle traffic. This must have contributed to benefits due to more physical activity, less air pollution, less traffic noise, less oil consumption, etc.” (page 14).

Following one year after this paper, an unpublished study by Agerholm et al. (2008) used a similar approach, performing a before-after study with a comparison group in medium-sized and large towns in western Denmark. However, unlike the Jensen study, the expected results for the segments with cycle tracks were not further adjusted based on comparison to a prediction model. Although the study reported an increase in bicyclist injury collisions associated with cycle tracks, it did not control for bicyclist volume/exposure. Also, among the intersection collisions evaluated in the study, the authors chose to exclude those that occurred at the far-side of the intersection. The reason for this was a desire to include only collisions that could be influenced by the presence of the cycle track. However, the presence of the cycle track on the near- and far-side of the intersection generally corresponds with a space of roughly equal width through the intersection. This additional cycling space in the intersection could influence the likelihood of a bicyclist being hit from behind on the far side of the intersection. The study may have had different results if it included all collision types and were adjusted for exposure to assess relative risk.

4.5. *Studies of two-way cycle tracks*

Studies specific to two-way cycle tracks are reviewed in this section, separate from the one-way facilities, because, as the studies have found, two-way cycle tracks generally have more intersection collisions than one-way tracks. The results of these studies should therefore not be extrapolated for application to one-way cycle tracks.

The studies reviewed below were all conducted in either Finland or Canada. This is because the cycling infrastructure of towns and cities in Finland is characterized by two-way cycle tracks, while Montreal, Canada, is the only North American city that has been subjected to a published study of its cycle tracks, which are also two-way. In the United States, major cycle track facilities have only been recently constructed and have yet to have published evaluations. The authors of this review found only one U.S. study of two-way side path safety, by Petritsch et al. (2006), but chose not to include it in this review because it evaluated suburban and semi-rural paths rather than urban cycle tracks.

An unpublished study by Pasanen and Rasanen (1999) conducted in Helsinki, Finland, found that cycling on a two-way cycle track was more likely to result in a collision, per mile traveled, than cycling in the street. It reported that two-way cycle tracks accounted for 45% of cycling kilometers and 56% of injury collisions. It also reported that the risk of a collision is three times higher for cyclists crossing a street coming from a cycle track than for cyclists crossing after approaching from the street, which indicates that the risk of injury between intersections is much less for two-way cycle tracks given the above-described overall results. Without accounting for injury severity, the study may have thus underestimated the benefits of two-way cycle tracks in reducing severe injuries and fatalities associated with overtaking (hit from behind) collisions, which is the most common cause of fatal bicyclist collisions in urbanized areas (McCarthy and Gilbert, 1996).

An unpublished and undated paper written by Pasanen for the Helsinki City Planning Department (Pasanen, undated) presents the same findings regarding the collision risk of two-way cycle tracks. However, the same study found significant differences in the bicycling fatality rates for different European countries, with The Netherlands, Sweden and Denmark having the lowest rates (1.6–2.3), Finland and Great Britain in the middle (5.0 and 6.0), and Italy on the high end (11.0), per 100 million kilometers traveled. The Netherlands, Sweden and Denmark are known for their bicycling networks and one-way cycle tracks, while Great Britain and Italy lack cycle tracks.

Note that, since the 1990s, the annual number of fatal cycling crashes has steadily declined in Finland, while the number of annual cycling trips has increased (Nordic Council of Ministers, 2005; Finland National Statistical Service, 2011). Assuming that the City of Helsinki provides a large proportion of the country's cycle trips and that the City has had similar trends in trips versus crashes, these trends may be due in part to a safety-in-numbers effect as the cycle tracks have attracted more bicyclists and may have improved the safety performance of these facilities over time such that the study results would be different today.

A study by Rasanen and Summala of data from four Finnish cities (Sept, 1998) attempted to shed light on the causes of collisions associated with two-way cycle tracks. It found that the most frequent collision type was that of a driver turning right while a bicyclist was approaching perpendicularly from the right. This was because drivers turning right were looking left for other cars before proceeding, as also found in a 1996 study by Summala et al. (described below). Only 11% of drivers noticed the cyclist before the collision, while 68% of cyclists had seen the motorized vehicle.

A more recent study, jointly conducted by U.S. and Canadian researchers (Lusk et al., 2011), specifically examined the safety

effects of two-way cycle tracks constructed in Montreal, Canada. It compared six cycle tracks with reference streets in estimating the relative injury risk. According to the authors, one reference street was a continuation of the street with the cycle track, while each of the other reference streets ran parallel to the street with the cycle track and had the same endpoint, thereby having the same intersection frequency and about the same cross traffic. The study found that the 2.5 times as many bicyclists used the cycle tracks compared with the reference streets and that the relative risk of injury riding on the cycle tracks was 0.72 compared with using the reference streets. The strengths of this study are that it controlled for exposure and included all collision types, as well as its importance as the only published study on the safety of urban cycle tracks in North America. The limitations of the study are that it did not provide a before–after examination of the streets where cycle tracks were constructed and, as the authors acknowledged, did not look at injury severity.

Another North American study compared cycling injury risks of fourteen route types and other route infrastructure features in Toronto and Vancouver, Canada. It found that cycle tracks had the lowest injury risk, at about one-ninth the risk of major streets with parked cars and no biking infrastructure (Teschke et al., 2012). The study recruited nearly 700 residents injured while cycling and treated in the emergency departments of hospitals in Toronto or Vancouver. Participants were interviewed to trace the route of the injury trip and locate the injury site. As the authors described, “A case-crossover research design compared route infrastructure at each injury site to that of a randomly selected control site from the same trip.” The probability that a control site with a specific infrastructure type would be selected was proportional to its share of the trip length. One of the key findings of the study was that sidewalks and multiuse/shared use paths presented higher risks than cycle tracks and bike-only paths, which the authors speculated helped to explain why this study had more favorable results for cycle tracks than other North American studies did for off-street paths as a whole.

A key strength of this study is that it evaluated relative risk and focused on injury crashes, while a primary limitation is that it excluded fatalities and head injuries that caused the potential participant not to remember the crash. However, these were a small number of cases relative to the pool of participants. Another key limitation of the study is that it did not assess the affect of cycle tracks on injury severity relative to other infrastructure types.

4.6. *Studies that examined the effectiveness of safety measures for intersections*

4.6.1. *Studies of intersection safety measures for one- and two-way cycle tracks*

An unpublished study conducted between 1983 and 1987 by Leden (1990) surveyed school children in Sweden, Finland and Norway. The children were asked where they cycle and about the traffic collisions in which they had been involved. The authors then developed a model to describe how street design and traffic control affect collision risk. The study found that effective measures to improve safety include ending the cycle track or path before an intersection, locating cycle crossings less than 3 m from the parallel road, giving a special bicyclist phase on crossings controlled by traffic signals, and grade separating crossings.

4.6.2. *Studies of intersection safety measures for one-way cycle tracks*

A paper by Linderholm, based on a study carried out in Sweden (1992), showed that cyclists going straight ahead on a cycle track were 3–6 times more likely to run a red light than cyclists on the street, and that red running cyclists were 2.3 times more likely

to have a collision than cyclists crossing with a green indication. However, for left-turning cyclists, those traveling on the street are 4 times more likely to have a collision than cyclists on a separate track. The author therefore recommended that cyclists be directed from the track onto the street about 30 m before the intersection, but that, if left-turning cyclists exceeded 20% of the cyclists approaching the intersection from a given direction, the track continue to the intersection. Linderholm also analyzed the effect of an advance stop line for motor vehicles at signalized intersections in combination with converting the cycle track to a cycle lane 20–30 m before the intersection. The analysis indicated that this treatment reduced the collision risk for cyclists crossing the intersection by about 35%, primarily due to safety improvement for cyclists turning left.

An unpublished paper by L. Herrstedt et al. (1994) based on Danish data for the years 1988 through 1991 reported that about two-thirds of cyclist injuries in urban areas happen at intersections and that the major intersections are particularly hazardous for cyclists. It also acknowledged that Danish, Swedish and Dutch experiences have shown that cycle tracks can in some cases result in a higher frequency of collisions at major intersections. The paper described the solution of truncating cycle tracks 20–30 m before intersections, where they become bicycle lanes, but stated that this solution is unpopular among cyclists because it makes them feel less safe. As an alternative, the paper proposed two different measures. One is to convert the cycle track to a bicycle lane as described, but with an advance stop line in the motor vehicle lanes 3–5 m behind where cyclists stop at the intersection in order to increase the visibility of cyclists to motorists. The other measure is the use of rumble pavement to direct cyclists on the track closer to the motor vehicle traffic in advance of the intersection, in order to increase the visibility of the cyclists to motorists, and then to direct the cyclists back to the original lateral position of the cycle track at the intersection in order to give motorists and cyclists more time to react to each other. The results showed that cyclists and motorists had more early reactions to each other and that near-misses were reduced, which indicated a likely improvement in traffic safety.

A before- and after-study by Garder et al. (1998), examined the effect of raising urban bicycle crossings at various locations in Gothenburg, Sweden. The observed bicycle collision frequency (collisions per month) after installing the raised bicycle crossings was 67% of the frequency before the crossings were raised. Since the raised crossings attracted more than 50% more cyclists, the reduction in collision risk per cyclist would actually be greater than 33%. Also, the study found that the raised crossings reduced motor vehicle turning speeds on average by 40%, indicating that the injury risk (as opposed to collision risk) and serious injury risk would be reduced even further. However, this study, like the 1994 Garder study, also included the opinions of cyclists and “experts” and combined those with the observed results using a Bayesian approach to develop a risk estimation model. This led to the development of an estimate of a 20–30% risk reduction from raised cycle crossings. The extent to which the results in the field should be weighted against subjective opinions seems rather speculative and, in fact, gave an answer that was much more conservative than the actual results observed in the field.

A follow-up paper by Leden et al. (2000) used a similar approach in examining the Gothenburg raised bicycle crossings, concluding that the safety per cyclist was improved by 20%. The paper noted that the decrease in automobile speeds was offset by an increase in cycling speeds and instead attributed the safety improvement to an increase in cycling flow (safety in numbers) (Jacobsen, 2003). However, this was based on the expert opinions, without empirical evidence to substantiate this claim. Also, as the 1998 Garder paper pointed out, although the collision risk attributed to speed may remain constant, the injury risk should be reduced because

automobile turning speed would have more of an influence on injury risk than bicycle speed. Overall, the estimated 20% improvement in safety was, like in the 1998 Garder paper, based partially on expert opinions and was much more conservative than the actual observed effect of the raised crossings.

Later, Jensen conducted a study of the safety effect of blue cycle crossings in Copenhagen, Denmark (2008), using the same methodology as in his other 2007 study described above. Based on a comparison to the effect predicted by Jensen's model, the study found that the blue cycle crossings were associated with decreased collisions and minor, severe and fatal injuries at intersections with only one blue crossing, and with decreased collisions (injuries not reported) at intersections with two blue crossings if the intersection had no more than three legs. Blue cycle crossings were also found to be more effective at smaller intersections and ones with a lower traffic volume. The author hypothesizes that, when multiple cycle crossings are marked in blue, the driver's focus is too dispersed among the different crossings and the attention to any one crossing is too diluted for it to be effective.

Another study examining the safety effect of intersection treatments was produced by Schepers et al. using data from The Netherlands (2011). It found that the collision probability is decreased at intersections that have raised bicycle crossings or other speed reducing measures for traffic turning from the major road to the more minor road. The authors estimated that the cyclist's collision risk is reduced by 51%. The study also found that two-way cycle tracks are associated with greater collision risk (controlling for exposure). Perhaps surprisingly, the results indicated that "well marked" and reddish colored cycle crossings are also associated with greater risk. One limitation of this study, however, is that it was not a before–after evaluation. Locations treated with high-visibility and colored markings may have already had more safety problems, calling into question whether the markings themselves reduced safety. However, the study does point to the likelihood that raised crossings are more effective than markings alone.

4.6.3. *Studies of intersection safety measures for two-way cycle tracks*

A study by Summala et al. (1996) examined collision types associated with two-way cycle tracks in Helsinki and found that the primary collision type at T-intersections (where a minor street ends at a junction with a major road) was that of cyclists approaching from the right on the primary street or road while the motorist was attempting to make a right from the minor street. In most cases, the motorist did not see the cyclist because the motorist was looking left for an opening in traffic and did not look to the right for a cyclist before proceeding. The study then tested the intersection scanning behavior of motorists after safety countermeasures were employed at intersections. The results suggested that measures to reduce motor vehicle speeds (speed bumps and elevated bicycle crossings) and stop signs placed in advance of the intersection were effective at increasing the proportion of drivers that scanned to the right. (Note that in Northern Europe use of yield control is common where minor streets meet major ones. Also, many minor arterials and collector roads in Helsinki are not priority roads at all; drivers from these minor streets ending at T-intersections do not have to yield to vehicle traffic from the left along the major road.)

Given the relatively high cost of speed bumps and raised cycle crossings, and therefore the impracticality of employing them widely in a short timeframe, Rasanen and Summala conducted a follow-up study (Feb. 1998) to test the effectiveness of red bicycle crossings combined with advance on-road bicycle warning markings at T-intersections in Helsinki where a two-way cycle track runs along the priority road (as described in the preceding paragraph). The study found that a triangular warning sign with a bicycle stencil

painted on the pavement in advance of the intersection increased the proportion of drivers looking right, but did not decrease the proportion that only looked to the left. (The proportion of drivers looking only straight ahead thus decreased). When this treatment was combined with a red bicycle crossing, the proportion of drivers looking only to the left was reduced by between 10 and 50 percent. This improvement in motorist scanning behavior indicated a likely improvement in safety for cyclists.

5. Results

Table 2 shows the factors to consider when interpreting the results of the studies reviewed here. Key considerations are whether the study controlled for exposure, examined injury severity and included crashes both at and between intersections. Studies that did not control for exposure would tend to overstate the collision rate and risk to individual cyclists associated with cycle tracks because they would not account for the increased amount of cycling after a cycle track is constructed. Studies that did not examine injury severity would tend to underestimate the benefits of cycle tracks by treating all collisions as being equal and not capturing the safety benefit of eliminating the overtaking (hit from behind) collision type, which is the most common cause of fatal bicyclist collisions in urbanized areas (McCarthy and Gilbert, 1996). Comparative studies limited to intersection collisions would also tend to underestimate the benefits of cycle tracks by not accounting for the difference in mid-block overtaking collisions.

Other important considerations are whether the study measured results using empirical data to compare streets with and without cycle tracks. Studies using citywide collision or injury outcomes can suggest that better performing cities have safer bicycle facility types, but do not pinpoint the relationship between each facility type and the outcome. Studies that combine opinion surveys, or surveys based on recollection, tend not to be as reliable as empirical studies for showing the relationship between the facility type and the outcome. Studies that use a traffic model to establish an expected reduction in crashes can penalize cycle tracks for decreasing the auto traffic volume if they do not thereby decrease the bicycle crashes as much as expected.

Ideally, cycle track safety studies would examine a set of streets using before and after data on serious and fatal injury collisions occurring both at and between intersections while controlling for the trend in such collisions and bicyclist exposure. None of the studies of overall cycle track safety reviewed here met all of those criteria. The 2011 study by Lusk et al. came close in that it included only injury and fatal collisions and controlled for exposure, although it compared streets with cycle tracks to reference streets rather than being a before–after study. It is also the only study on the safety of cycle tracks located for this paper that was both peer reviewed/published and controlled for bicyclist exposure other than the 1994 Garder study, the results of which were confounded by opinion survey responses, and the 1988 Dutch studies (Wegman and Dijkstra, 1988; Welleman and Dijkstra, 1988), which were confounded by moped use of cycle tracks in the Netherlands at the time. The results of the study by Lusk et al. are therefore included in Table 3, which provides crash modification factors for cycle track treatments.

A number of the studies on the safety of intersection treatments for cycle tracks did provide useful crash modification factors for these treatments. These indicate that, even if concerns about the intersection safety of cycle tracks were valid when controlling for exposure, they can be mitigated. These crash modification factors are shown in Table 3 for the published studies reviewed here.

In order to understand the significance of these studies as a whole, it is also important and useful to look at the historical trend and motivation for them. When the Dutch had concerns about

Table 2

Summary of literature review: considerations in interpreting study results.

Study author(s)	Controlled for exposure	Included all crash types	Results based on empirical data	Before/After study	Examined injury severity	Published study	Notes
Cycle track safety studies							
West Berlin Police (1987)		✓	✓	✓	✓		c
Bach et al. (1988)		✓	✓	✓			c
Wegman and Dijkstra (1988)	✓	✓	✓			✓	d
Welleman and Dijkstra (1988)	✓	✓	✓			✓	d
Garder et al. (1994)	✓			✓		✓	e
Larsen (1994)		✓	✓			✓	c
Eilert-Petersson and Schelp (1997)		✓	✓			✓	c
Pasanen (undated)	✓	✓	✓	✓			
Rasanen and Summala (Sept 1998)	✓	✓	✓			✓	
Pasanen and Rasanen (1999)	✓	✓	✓				
Jensen (2007)	a	✓	✓	✓	✓		f
Agerholm (2008)		✓	✓	✓			c
Lusk et al. (2011)	✓	✓	✓			✓	
Studies of effectiveness of intersection safety measures for cycle tracks							
Leden (1990)	✓	NA					e
Linderholm (1992)	✓	NA	✓	✓		✓	
Herrstedt et al. (1994)	✓	NA	✓	✓			
Summala et al. (1996)	✓	NA	✓	✓		✓	
Garder et al. (1998)	✓	NA	✓	✓		✓	e
Rasanen and Summala (Feb 1998)	✓	NA	✓	✓		✓	
Leden et al. (2000)	✓	NA		✓		✓	d
Jensen (2008)	✓	NA	✓	✓	✓	✓	f
Schepers et al. (2011)	✓	NA	✓			✓	

NA: not applicable because, by design, these studies were about intersection safety measures.

a Increase in number of cyclists factored into model of expected crashes, but change in cyclist risk, based on collisions/injuries relative to exposure, not evaluated.

b Results for severe and fatal injury collisions were not statistically significant.

c Lacked cyclist volume (exposure) data/did not assess relative risk.

d Included moped use of cycle tracks (later prohibited).

e Combined opinion survey results with empirical data.

f Results evaluated by comparison to prediction model.

Table 3

Crash modification factors for cycle track intersection treatments; published, peer reviewed studies^a

Treatment/device	Crash modification factors or change in behavior	Study author/date	Statistical significance ^b
One-way cycle tracks			
Raised cycle crossings	<u>Intersections ± Links</u> Cyclist crashes: -33% (greater reduction in cyclist risk due to increased biking)	Garder (1998)	Statistical significance not reported
	<u>Intersections</u> Cyclist crash risk: -51%	Schepers (2011)	RR: 0.49 (0.32–0.77 at 95% CI) P-value < 0.01
	Vehicle turning speeds: -40%	Garder (1998)	Statistical significance not reported
Convert cycle track to cycle lane 20–30 m in advance of intersection with use of advance stop line for motorists 3–5 m behind waiting cyclists	<u>Intersections</u> Cyclist crashes: -35%	Linderholm (1992)	Statistically significant
Colored cycle crossings (blue) through intersections	<u>Intersections</u> 4-way/T colored crossing: -10% overall crashes -19% overall injuries	Jensen (2008)	RR: .90 (0.80–1.02 at 95% CI)
Two-way cycle tracks			
Raised cycle crossings	<u>Intersections</u> Increase proportion of drivers who scan to the right	Summala (1996)	Small n; Statistical significance not reported
Colored cycle crossing (red) in combination with bicycle stencil in advance of intersection on cross-street approach	<u>Intersections</u> Increase drivers scanning to the right: +31% (increased from 9% to 40% of drivers)	Rasanen and Summala (1998b)	P-value < 0.001

a Only published studies controlling for exposure and based on collision and/or injury data are included. Thus only raw crash results (without adjustment based on opinion surveys) are included for Garder.

b RR: Relative Risk; CI: Confidence Interval.

the safety of their cycle tracks in the late 1980s, their studies showed that much of the problem had to do with moped use of the facilities and with intersection design. Their response was to employ intersection safety measures, particularly raised crossings, and eventually to require that moped riders use the street in urban areas. The 2011 study by Schepers et al. showed the safety benefit of the raised cycle crossings. Meanwhile, on a national scale, the statistics were moving in the direction desired by planners and policy makers: bicycle kilometers traveled per inhabitant continued to increase while the number of cycling fatalities continued to decline (Pucher and Buehler, 2008a,b). The Dutch satisfaction with cycle tracks as a bicycle facility and the favorable statistics meant that there was little or no reason to continue to study them, hence the lack of follow-up studies to prove their benefit relative to cycling in the street.

A similar story has played out in other Northern European countries. In Denmark and Sweden, while some studies pointed to problems at intersections, follow-up studies found specific intersection safety treatments to be effective. Studies in Finland found that the two-way cycle tracks there were less safe than the one-way tracks found in other Northern European countries, but that certain intersection safety measures are effective at reducing crashes. These results, together with the effects of other cycling safety treatments, are borne out on a national scale in The Netherlands, Denmark and Finland, where fatalities have declined even as cycling increases (Nordic Council of Ministers, 2005).

Finally, it is worth noting that The Netherlands, Denmark, Sweden and Germany have much higher rates of cycling as a share of trips, and much lower fatality rates per kilometer cycled, than does the USA, with its relative lack of separate facilities for cycling in urban, congested conditions. The percent of trips made by bicycle ranges from 9 to 11% in Germany, Sweden and Finland, 18% in Denmark, and 27% in the Netherlands, compared with only 1% in the U.S. Meanwhile, a cyclist in the U.S. is over five times as likely to be killed as one in the Netherlands, nearly four times as likely to be killed as one in Denmark or Sweden, and three and a half times as likely to be killed as one in Germany, per kilometer cycled (Pucher and Buehler, 2008a).

Cyclists in these Northern European countries represent virtually all segments of society. Women have about twice as high a share of bicycle trips in Denmark, Germany and the Netherlands as they do in the U.S. (45–55% compared with 24%). Also, a much higher proportion of local trips made by the elderly is by bicycle in Denmark, Germany and the Netherlands compared to the situation in the U.S. (Pucher and Buehler, 2008b).

These indicators result from programs and policy initiatives that include the provision of facilities that make cycling accessible, safe and comfortable for a wide range of people. The outcome is a relatively connected cycling network with facilities geared toward specific traffic conditions, ranging from traffic-calmed streets to bicycle lanes to cycle tracks and associated intersection treatments for routes with higher traffic volumes and speeds (Pucher and Buehler, 2008a,b). In contrast, the majority of cities and towns in the U.S. either lack bicycle facilities, or have taken a one-size-fits-all approach wherein, on city streets, only bike lanes immediately adjacent to traffic, without any physical separation or barrier, are provided regardless of the traffic volume or speed.

6. Conclusion

The literature reviewed indicates that one-way cycle tracks are generally safer than two-way and that, when effective intersection treatments are employed, constructing cycle tracks reduces collisions and injuries. The evidence also suggests that, when controlling for exposure and including all collision types, building

one-way cycle tracks reduces injury severity even when such intersection treatments are not employed. However, this needs to be more thoroughly studied.

Intersection treatments appearing to be effective are:

- Bringing the cycle track closer to the parallel auto traffic at the intersection approach to increase the visibility of cyclists to motorists.
- Placing an advance stop line for motorized traffic at least 20 m before the intersection.
- Raising cycle crossings to the level of the cycle track, essentially providing a speed hump, to lower vehicle turning speeds and reduce injuries to cyclists.
- Providing dedicated cyclist signals to separate the cyclist through-movement from turning vehicles (although this has generally not been studied formally, probably because it already provides a temporal separation between motorists and cyclists).

The results of studies of the safety benefit of colored cycle crossings are more mixed. They appear to improve safety if only used on one side of a four-sided intersection. The reason seems to be that they lose their conspicuity if applied on multiple legs of an intersection.

The most common shortcoming in the state of the literature was the failure to address injury severity. This is a crucial distinction given that fatalities and permanently disabling injuries are, by definition, irreversible and are much more devastating to individuals and society than are minor or temporary injuries. The studies that have examined severity indicate that constructing cycle tracks reduces injury severity. This makes sense, given that cycle tracks appear to eliminate the collision types that occur midblock such as riding into a car door and being hit from behind, the latter having the highest fatality rate.

Another common shortcoming was the failure to account for exposure, distorting the relative risk associated with cycle tracks. Standard traffic-engineering practice is to calculate automobile crash rates relative to traffic volume in order to assess risk. This should also apply to bicycle crashes. The potential increased numbers of bicycle collisions culminating from more bicycle riding needs to be balanced against the reduced number of auto occupant collisions along with the individual health benefits of increased physical activity.

Future safety studies, particularly before and after studies, should therefore separate fatal and disabling injuries from minor ones, and should present injury rates and relative risk accounting for the change in the numbers of cyclists. More analysis on the change in collision type distribution and the resulting severity rates by collision type would also be useful. This would show the degree to which a shift occurs from bicycle-auto collisions to collisions between nonmotorized modes (bike-bike and bike-pedestrian) and its relationship to reducing impact speeds and injury severity. Earlier research has suggested that this is what occurs, but has not focused so much on that particular question.

Finally in the U.S., where the obesity epidemic and its health consequences and costs are well documented, the environmental and public health benefits of increased cycling should be a focus of research and policy development to provide the infrastructure needed to attract people to cycling while minimizing injuries. The lack of any American studies indicates how little developed and understood cycle tracks are in the United States. For cycle tracks to be developed and studied in the U.S., American design manuals must first acknowledge that cycle tracks are a distinct and unique bikeway type; not a variation of a shared use path. Then American manuals should provide appropriate design guidance. This will lead to the development of facilities and provide locations for needed research into U.S. applications of intersection safety

treatments given typical American intersections and driver behavior. Although some local agencies are proceeding with designing and constructing cycle tracks in the absence of such guidance, most local agencies will wait until cycle tracks are an official option. Until this occurs, the U.S. will be lacking in cycle track locations to study, leading to a vicious cycle in which design innovations are slowed and the urban bike mode share remains low.

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Vice Mayor Benzan stated that he has many question to ask. How will the Bike Plan be incorporated into the Master Plan process? He spoke about implementing stripping the streets. Ms. Farooq explained the integration of this plan will be put into the Master Plan. Vice Mayor Benzan stated that the Green Street Garage needs to be reconstructed and could be the first bike/car parking facility. Now is the time to redevelop this garage. He also stated that dedicated bus lanes are critical for the City. The bus lanes may also act as a bike lane. He stated that in Netherland they wanted people to bike to live health lives and not focus on reducing the carbon foot print. He stressed the importance of education. He stated that The Port could be a pilot program to connect streets to the Grand Junction. He wanted this to be the first bike superhighway. This will be costly for the City when there are other areas that require attention. This has to work in conjunction with other communities. He spoke about the importance of driver education. He felt more questions and more deliberation is needed.

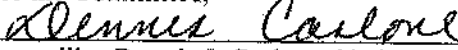

Councillor Mazen stated that the Bike Plan is well received by the biking community. This plan has to be taken in context with other plans going on in the City. He spoke about problems that are being attributed to bikers and that all sides in the argument tend to be right. Protected bike lanes and Vision 0 must be taken seriously. He stated that he can see the accident before it happens and he has been doored. The way that trucks and busses are handled on Massachusetts Avenue are disasters waiting to happen. He wanted to be biking safer street quickly.

Councillor Carlone stated that he was impressed with the scope, details and the next steps of the report. This is a positive movement in the City. These improvements are minor with construction.

Councillor Carlone thanked all attendees for their participation.

The hearing adjourned at 5:43 PM on motion of Vice Mayor Benzan.

For the Committee,


Councillor Dennis J. Carlone Chair 
Transportation and Public Utilities Committee